Towards Developing an Agent-Based Model of Price Competition in the European Pharmaceutical Parallel Trade Market

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Abstract. The European pharmaceutical parallel trade refers to the practice of purchasing pharmaceutical products in one European Union (EU) member state at a lower price and reselling the products in another EU member state at a higher price. In the pharmaceutical market, pricing strategies are of utmost importance as the market structure and regulations allow only the lowest-priced product to gain market share, making it imperative for players to optimize their pricing decisions in order to remain competitive. Therefore, developing a dynamic and data-driven pricing strategy that takes into account market conditions, competitors' behaviors, and regulatory compliance is of interest to players involved in this market. In this paper, we demonstrate the potential of agent-based modeling as a tool for integrating mathematical modeling and economic concepts and investigating targeted pricing strategies in the pharmaceutical parallel trade market. We achieve this by utilizing agent-based modeling to evaluate and compare multiple pricing strategies through simulation. We aim to identify the challenges associated with developing a dynamic pricing approach in this complex market by showcasing the effectiveness of agent-based modeling. We contribute to the understanding of pricing strategies and their implications in the pharmaceutical parallel trade market.

Keywords: Agent-based modeling and simulation · Pricing strategy · Price competition · Pharmaceutical parallel trade

1 Introduction

The European pharmaceutical trade market incorporates the practice of parallel trade, also known as parallel importing, in which patented pharmaceutical

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products are purchased in one EU member state at a lower price, repackaged to comply with another EU member state market's local legislation, and then resold in the destination state at a higher price. This is made possible by the EU's single market that allows for free movement of goods between member states [6]. There are several players involved in the pharmaceutical parallel trade market, including original manufacturers (also known as originators), parallel importers, wholesalers, retailers (pharmacies, supermarkets, and online retailers), and regulators. In this market, each player plays a unique role and interacts with others to bring pharmaceutical products to the end-users. The parallel trade market can benefit consumers as it increases the availability of cheaper medicines. However, it can also have a negative impact on pharmaceutical companies' profitability and competitiveness [7].

Decision-making processes in the pharmaceutical trade market are challenging as they involve multiple factors, such as market demand, dynamic supply chain, balancing profitability and affordability, regulations, and price competition. Investigating and quantifying even one of these factors could be a challenging assignment. For example, the price competition between parallel traders and the originator in a country's market can be intense, as all parties are vying for a share of the market and profits, whereas the parallel import framework allows parallel traders to offer the same products to consumers at a lower price than the original manufacturers [5]. The pricing strategy for players involved in the pharmaceutical parallel trade market is a complex process that takes into account various factors such as the price of the product in the origin country, transportation and logistics costs, tariffs, taxes, and the market demand in the target country.

Agent-based modeling and simulation (ABMS) enable the possibility to evaluate, analyze, and predict behaviors and interactions, especially under uncertainty as is common in complex processes such as economics interactions [19]. ABMS has advantages over other forms of modeling, like mathematical modeling, by facilitating the design of agents with relatively more autonomy, and has been applied in the field of economics for a number of purposes, such as analyzing market dynamics, the impact of regulations, and the study of financial markets [18]. Furthermore, running simulations that account for multiple initial assumptions can offer insights to guide decision-making, ultimately contributing to the maximization of economic efficiency and stability. In our previous work, we developed a simple agent-based model of the pharmaceutical parallel trade market involving two countries and demonstrated how this model could be beneficial for players involved in this market and how economists can use the model to investigate the pharmaceutical parallel trade market [9,10].

In the first agent-based model of the pharmaceutical parallel trade market, the competition between players is modeled as a Cournot competition where players compete to get a larger market share only by adjusting their sell quantities [10]. In subsequent work, we developed an initial pricing function for agents to investigate and demonstrate the ability of an agent-based model to simulate multiple scenarios of parallel trade of pharmaceuticals [8]. The primary objective of this study is to investigate the effect of various pricing strategies on the profitability of agents participating in the price competition of the pharmaceutical parallel trade market, through an agent-based modeling approach. The study aims to identify the challenges and opportunities associated with modeling pricing strategy and their implications on the market.

The rest of the paper is structured as follows: In Sect. 2, we present the agent-based model of the pharmaceutical trade market. Section 3 describes the agent-based model specification of the case study. Results and discussion of the case study are presented in Sect. 4. Lastly, a summary and outlook of the paper are provided in Sect. 5.

2 Description of the Parallel Trade Market Model

In this study, we model the price competition among multiple parallel traders and a manufacturer (or direct sellers) in the Danish pharmaceutical market using agent-based modeling. Our research utilizes the agent-based model to study pricing strategies and key factors that influence pricing strategies for the participants of the pharmaceutical market.

Parallel traders import medicine from foreign countries, repackage it to comply with Danish regulations, and sell it for profit, whereas manufacturers sell medicine directly in the market. In Denmark, the prices of medicinal products are determined by pharmaceutical companies (parallel traders and manufacturers) and sold at the same rate by all pharmacies. The Danish Medicines Agency does not regulate the prices set by the companies but rather ensures that prices are updated every 14 days (fortnight) and reported to relevant parties. Every fortnight, pharmaceutical companies that wish to sell a particular medicine must establish its price. The company that offers the lowest price for a medicine will be the offered brand for that medicine at all pharmacies in Denmark. If the company with the lowest price cannot deliver the market demand, pharmacies will proceed to offer the product from the company with the second lowest price, and so on. The system of fixed prices and free market competition helps maintain low prices for medicinal products. This framework creates a level of stability in the market by setting limits on the number of packages a company can deliver [2,11].

This study extends our previous research [10] by expanding the agent-based model to account for the behavior of the players' pricing strategies during the price competition in the destination market. First, we describe the basis agent-based model of a pharmaceutical trade market that comprises two countries. Then, we define pricing strategies for the players involved in the market, resulting in an extended agent-based model of price competition in the market. The nature of price competition in the Danish pharmaceutical market is unique in that only the player with the lowest price can secure market share in a given fortnight, while others are unable to do so. Moreover, considering the narrow profit margin associated with parallel trading of pharmaceutical product and their expiry date, the decisions regarding timing and pricing can have a significant impact on participants' profitability. Consequently, it is crucial for participants in this market to explore and develop effective pricing strategies to gain an edge in the competition.

2.1 Agent-Based Model of Pharmaceutical Parallel Trade Market

Our agent-based model of the pharmaceutical parallel trade market is motivated by a game theory model of the parallel trade market between the United States and Canada and examines the impact of parallel trade on the profits of manufacturers and social welfare [17]. Two countries are involved in the game theory model, denoted as country I and country E as importer and exporter, correspondingly. The model commences with a pharmaceutical manufacturer (located in country E) negotiating the price of a patented medicine with the government of country I, which is modeled as Nash bargaining negotiation [16]. Subsequently, parallel traders purchase the medicine in country I and incur a transfer cost to repackage and move the medicine to country E. Then parallel traders compete with the manufacturer in the market of country E (where the manufacturer can sell the medicine at its desired price) to sell the medicine and maximize their profits, modeled using Cournot competition [4]. Cournot competition is an economic model that illustrates a business scenario wherein rival companies present a homogenous product and compete by determining their sales quantity in the market. The equilibrium price (P) for the medicine in the game theory model is calculated according to:

$$P = \begin{cases} \frac{1}{2}[1 - \frac{n(1-2(P_I+t))}{n+2}], & \text{if } P_I \le \frac{1}{2} - t \\ \frac{1}{2}, & otherwise \end{cases}, \tag{1}$$

where P_I is the price of medicine in country I, n is the number of parallel traders engaged in the market, and t is the transfer cost for parallel traders.

In the agent-based model of the pharmaceutical parallel trade market, we consider the environment to be the same countries as in the game theory model. The model has three types of agents, i.e., government, manufacturer, and parallel trader. The simulation of our agent-based model consists of multiple steps that model the behavior of the manufacturer and traders in the pharmaceutical market of the two countries, I and E. In each step, the manufacturer and the government set the medicine price in country I using the Nash bargaining result same as the game theory model. The manufacturer then sells the product in country I, while traders evaluate the profitability of participating in country E's market considering the transfer cost. If traders participate in the market, they compete with the manufacturer and each other to sell a quantity of the medicine of interest. The price of the medicine in country E is calculated using a linear demand function that depends on the total quantity sold and the market size. The revenues for the manufacturer and traders are calculated at each step by reducing costs associated with sales. The manufacturer and traders adjust their market shares to maximize their revenue in each step. Fig 1 provides a high-level overview of the agent-based model. The agent-based model demonstrates the capability to replicate equilibrium prices observed in the game theory model.

Moreover, it offers the advantage of convenient adjustment of model parameters for agents, such as transfer cost, enabling further investigation of the market dynamics.

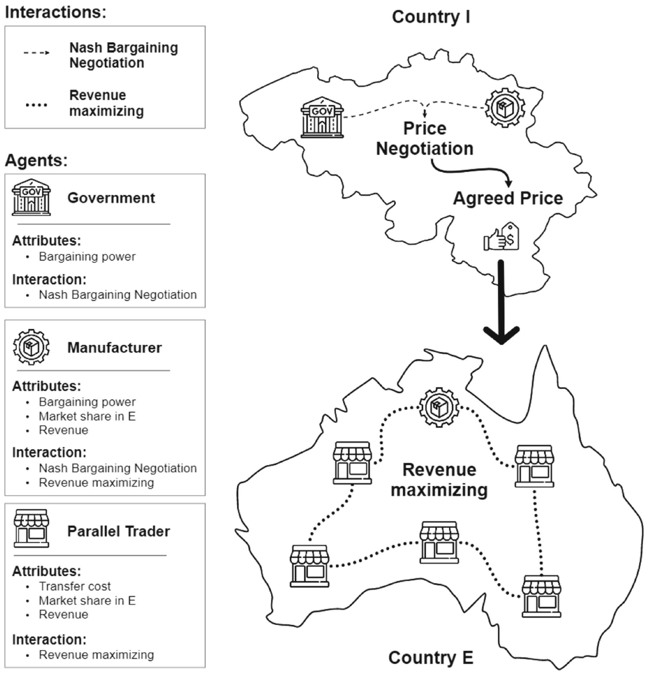

Fig. 1. Agent-based model of a pharmaceutical parallel trade market.

To modify our original agent-based model and investigate pricing strategies, we consider that the government and the manufacturer have already completed the negotiation, and the price of the medicine is fixed in country I (P_I). Parallel traders subsequently purchase the medicine at P_I. After incurring the transfer cost (t), parallel traders participate in price competition in country E by implementing individual pricing strategies that we elaborate on further in Subsect. 2.2. Through running multiple scenarios, we evaluate the effectiveness of each pricing strategy and investigate the impact of different criteria on price adjustment.

2.2 Pricing Strategy

Pricing is an important aspect of marketing and a crucial decision for businesses [3], as it is the only element that generates revenue. Developing a pricing strategy is an intricate task influenced by multiple factors, such as product type, company goals, and market trends. Different pricing approaches, such as price skimming, penetration pricing, bundling, promotion, and complementary pricing, work towards determining the optimal price level [12].

In our model, two distinct pricing strategies are employed by agents. The first strategy is cost-plus pricing, which is utilized by the manufacturer. This approach entails adding a margin to the cost of production of the medicine to determine its final price. Given the typical nature of the pharmaceutical market, where the demand for patented medicines is generally assumed to surpass the supply, it is reasonable to assume that the manufacturer would adopt a cost-plus pricing approach. In our model, the margin is calculated by considering a revenue margin parameter greater than zero. To determine the price, the revenue margin is multiplied by the cost of production and then added to the cost.

The second pricing strategy is employed by parallel traders, where they average a predicted price of the medicine and the price derived from the cost-plus pricing to arrive at their price for the next fortnight. Parallel traders utilize historical data to predict the market price for the next step. They can employ two methods to predict the market price: averaging the price of the market for the last K fortnights, or employing a linear regression model that considers demand, the prices of all players in the market, and the number of fortnight, to predict the price of the medicine for the next fortnight.

Every step or in the agent-based model represents a fortnight where all players involved in the market assess their revenue margin and adjust it based on their previous sales. They examine their revenue histories from the previous N fortnight and if their revenue in more than D fortnights were zero, which suggests that their price is not competitive, they reduce their revenue margin. Conversely, if they earned some revenue in more than T fortnights in the previous N fortnights, indicating the potential for higher profits with a higher price, they increase their revenue margin. The pseudocode presented in Algorithm 1 outlines a comprehensive pricing strategy for market participants.

Algorithm 1. Pricing algorithm for agents in the agent-based model of the danish pharmaceutical market.

if Zero revenue for over D fortnights out of the last N: **then**
    Reduce revenue margin
else if Positive revenue for over T fortnights out of last N: **then**
    Increase revenue margin
else
    Keep current revenue margin
end if
$\hat{P} \leftarrow$ Predicted price of the market
for Player in the market **do**
    $\overline{P} \leftarrow$ cost-plus pricing using revenue margin
    if Player is manufacturer: **then**
        $P \leftarrow \overline{P}$
    else
        $P \leftarrow (\overline{P} + \hat{P})/2$
    end if
end for

2.3 The Agent-Based Model of Price Competition

In this model, there are two types of agents, termed manufacturer and trader, and the environment is the market, where all agents compete to sell a patented medicine produced by the manufacturer. In the following, we present the model in a structured manner, according to the guidelines in the Macal and North tutorial [13].

The first step towards presenting the model is defining the agents set, including agents' attributes and the rules governing their behavior. Both manufacturer and trader agents have eight attributes: 1) Warehouse capacity, which indicates their capacity to store the medicine in a market. 2) Stock, which indicates the number of available medicines in the warehouse. 3) Cost, which for the manufacturer indicates the production cost of the medicine, and for the trader indicates the total cost of buying, repackaging, and moving the medicine. 4) Revenue margin, which is used for cost-plus pricing. 5) Warehouse input, which indicates the number of medicine they are adding to their storage at every step. 6) N, which indicates the number of past fortnights they want to consider for revenue margin adjustment. 7) D, which is the a threshold for decreasing the revenue margin. 8) T, which is a threshold to increase the revenue margin. N, D, and T as presented in the pricing algorithm 1 are parameters representing the competitiveness of an agent in the market.

The second step is to define interaction rules. In each simulation step, both types of agents add a fixed amount of medicine to their warehouse, considering their warehouse capacity. Next, the agents will determine their selling prices for the upcoming fortnight, employing the pricing strategies outlined in Subsect. 2.2. The agent with the lowest price will then become the first seller in the market. If an agent can not provide the medicine for the market (the market demand is bigger than the agent's stock), the agent with the second lowest price start selling their medicine, and so on. Finally, all agents calculate their step revenue.

The Danish pharmaceutical market is the environment of our model. The environment has only one attribute, which is the market demand for medicine.

3 Case Study

In this section, we present the implementation details of the model presented in Sect. 2, aimed at evaluating the impact of pricing strategies and investigating agent-based model applications as a representative of the pharmaceutical market in Denmark. Here we are running our initial step towards developing an agent-based model of price competition. The model was developed using the Python programming language, and the Mesa library [14]. Our case study focuses on the competition surrounding the medication Apixaban, sold under the brand name Eliquis, which is used to treat and prevent blood clots and to reduce the risk of stroke in individuals with nonvalvular atrial fibrillation [1].

To generate the demand data for Apixaban, we utilized the Danish Health Data Authority website (https://medstat.dk/), which provides historical data on the volume of the drug sold in the Danish market. Given the limited size of the data set, we generated synthetic time series data from it using the SDV library [15]. We used the Gaussian Copula form SDV library, which is a tool to model the dependence structure of a set of variables by combining their marginal distributions with a copula function. This tool can generate synthetic time series data that captures the statistical characteristics of the original data. Additionally, the historical pricing data for the Danish market is publicly available from the Danish Medicine Agency (https://medicinpriser.dk/), which has a comprehensive record of the price development of all medicines on the market, updated on a bi-weekly basis since 1998. This data was employed to train the linear regression model used in the pricing strategy.

The parameter values utilized in the model implementation are based on available data for Apixaban. In our simulations, the warehouse capacity of the manufacturer was considered to be 10000 units of medicine, while that of the traders was set to 8000 units. The cost for the manufacturer was considered to be 400 DKK and 550 DKK for the traders. The initial revenue margin for the manufacturer was set at 0.7 and 0.3 for the traders. The warehouse input of the manufacturer in each step was set at 700 medicine units, while that of the traders was 450 medicine units. We use the variables N, D, and T in the model to define a player's competitiveness in the market in terms of their pricing behavior. Since the manufacturer operates in multiple countries, it was considered that they adopt a less competitive approach in the market and look over a longer window when adjusting their revenue margin. Therefore, the value of N was set at 20 for the manufacturer and less than 10 for the traders. D and T are thresholds that indicate the impact of market share on the pricing, with D and T being 2 and 18, respectively, for the manufacturer. This means that if the manufacturer does not have any sales in the market for 18 fortnights of the last 20, they will reduce their revenue margin by 0.01. If they have more than two sales in the last 20, they will increase it by the same amount.

The agent-based model of price competition in the pharmaceutical market of Denmark, developed in this study, provides a data-driven approach to investigating the market dynamics. This model offers the capability to examine the long-term impacts of various pricing strategies and provides insights into the behavior of market participants. Furthermore, the model can assist market players in exploring and determining the optimal approach to the market. In the following section, we will demonstrate the model's capabilities through multiple scenarios, highlighting its practical applications for players in the pharmaceutical market of Denmark.

4 Experiments and Results

The objective of the first scenario is to examine the impact of different pricing strategies on the total revenue of traders in the Danish pharmaceutical market. To accomplish this, four traders were considered, where two of them utilizing a simple price prediction technique by computing the average of the last five fortnights' prices and the other two employing linear regression to forecast the next fortnight's price based on historical data. To differentiate their characteristics, different values of N, D, and T were assigned to each trader. Here, one of the traders who employed averaging as their prediction technique was assigned $N = 8$ while the other was assigned $N = 5$. The same was done for the traders who utilized linear regression for price prediction. Additionally, $T = 4$ and $D = 2$ were assigned to all traders, while for the manufacturer, we set $N = 20$, $T = 18$, and $D = 2$. We simulated the model for 1000 replications, each lasting 1000 steps, with a synthetic time-series market demand generated in each replication, which varied and was independent of one run to another. We used the results of this simulation experiment to determine the impact of competitiveness on the total revenue of traders in the pharmaceutical market.

The simulation results showed that the trader who used averaging as the price prediction method and had $N = 5$ had the highest average revenue of more than 65 million for the whole 1000 steps. The second place was occupied by the trader who also employed averaging but had $N = 8$, with an average revenue of more than 64.2 million. The third place was held by the trader who had $N = 8$ and used linear regression as the price prediction method, with an average revenue of more than 64 million. The trader who had $N = 5$ and used linear regression as the prediction method had an average revenue of 63.8 million, which was the lowest among all traders.

The simulation result indicates that using averaging as the price prediction method was more beneficial for traders than linear regression under the current assumptions. Moreover, the results suggest that being more aggressive in changing the revenue margin is more profitable for traders when using averaging as the prediction method, whereas a different outcome might be expected when using another prediction method. This highlights the importance of investigating different approach combinations in a market, as the combination could have a completely different outcome than the expected one.

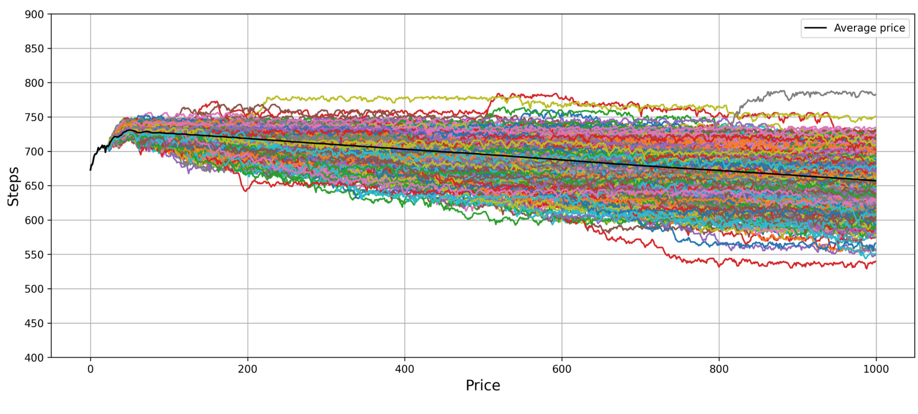

Fig. 2. Market price of the medicine over 1000 simulations.

Additionally, previous simulations can provide an overview of the future market price for the medicine while considering a projected demand for the medicine. Figure 2 illustrates the market price over simulations. Each colored line indicates an independent simulation, while the black one indicates the average of all simulations. In all simulations, the first 50 steps are historical data of prices. Since, in every simulation, a synthetic time-series market demand is generated, the medicine market price varies, which is aligned to the law of supply and demand in economics. However, the interesting observation from Fig. 2 is that price competition caused a diminishing trend in the market price over time.

The second scenario focuses on the manufacturer's behavior optimization in the Danish pharmaceutical market using our agent-based model. The simulation addresses a situation where the manufacturer aims to achieve the maximum profit per product sold in the Danish market over a period of two years, consisting of 104 fortnights. In this simulation, the manufacturer can adjust the parameters N, T, and S to reflect their anticipated market behavior and use historical data to predict the behavior of other market participants. Given the knowledge of the market's parameters, the manufacturer can then use the agent-based model to determine the optimal approach to attain their goal. In this scenario, we investigated the impact of varying values of parameter N on profit per product for the manufacturer in the Danish pharmaceutical market. Specifically, we considered values of 10 to 60 by step of 10 for N, where T was set as $N \times 0.9$ and D as $N \times 0.1$. To obtain robust results, we ran 500 simulations and calculated the 95% confidence intervals for profit per product for each value of N. The detailed results are presented in Fig. 3.

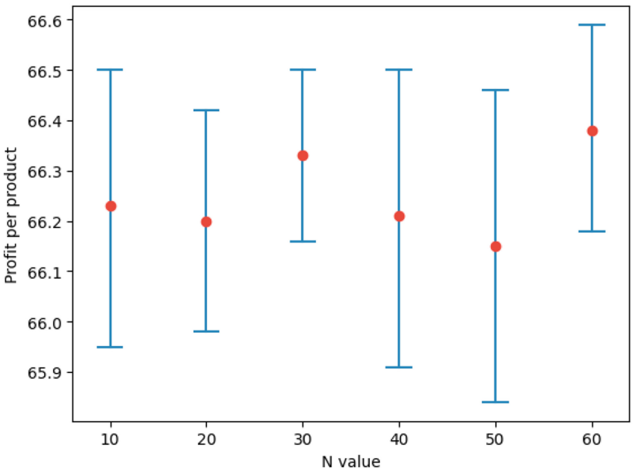

Fig. 3. Profit per product confidence interval for different values of N.

In the final scenario, we aimed to investigate the impact of new revenue margin adjustment criteria on traders' revenue in the Danish pharmaceutical market. Two additional criteria were introduced, one based on total revenue and another one based on volume sold, which were used to set the revenue margin values for each player. We ran the simulation for 1000 fortnights, repeated 1000 times, with one trader employing the previous criterion (count of zero revenue) explained in Subsect. 2.2, two using the new criteria, and the last trader considering all three criteria in an or clause (combined criterion). The results showed that the previous criterion, where traders only adjusted their revenue margin based on the number of zero revenue fortnights in the previous N fortnights, was the most profitable. The combined criterion was the second most profitable, while the total revenue and volume sold criteria ranked next. We also analyzed the profit per product for each trader and observed a similar order, with the gap between the first and second place being less than one. Our findings suggest that considering total revenue and volume sold does not necessarily lead to better pricing strategies for traders in the Danish pharmaceutical market, while employing the zero revenue count is the most profitable approach. Figure 4 provides a visualization of the 95% confidence intervals of total revenue and profit per product for all criteria.

5 Summary and Outlook

In this paper, we present an agent-based model of price competition in the Danish pharmaceutical market between a manufacturer and parallel traders. We demonstrated how this model can be used to analyze the long-term impact of pricing strategies on the market. Furthermore, the model facilitates participants in comprehending the behaviors of other market players in a structured and data-driven fashion by employing data-driven parameters. This model is an important step towards developing a data-driven model of price competition in the Danish pharmaceutical market, allowing players to explore optimal approaches to engage with the market. The presented model enables players to fine-tune their behaviors, particularly their pricing strategies, in order to achieve specific goals.

We ran multiple what-if scenarios with our agent-based model of the market to investigate the impact of different parameters on the players' revenue and profit per product. In our first simulation experiment, we investigated the impact of different pricing strategies on the traders' total revenue. In our second simulation experiment, we showed that the manufacturer could optimize their behavior in the market using our agent-based model to maximize their profit per product on sales. In our last simulation, we illustrated the impact of revenue margin adjustment criteria on total revenue and price per product of traders.

Our agent-based model of price competition in the Danish pharmaceutical market has the potential to become an effective tool for players to optimize their pricing strategies and understand their competitors' behavior. Our simulations indicate that the choice of price prediction method can have a significant impact on traders' total revenue. In this work, we explored and experimented with multiple pricing strategies and investigated various factors affecting the strategy. It is essential to acknowledge that the model presented in this study has yet

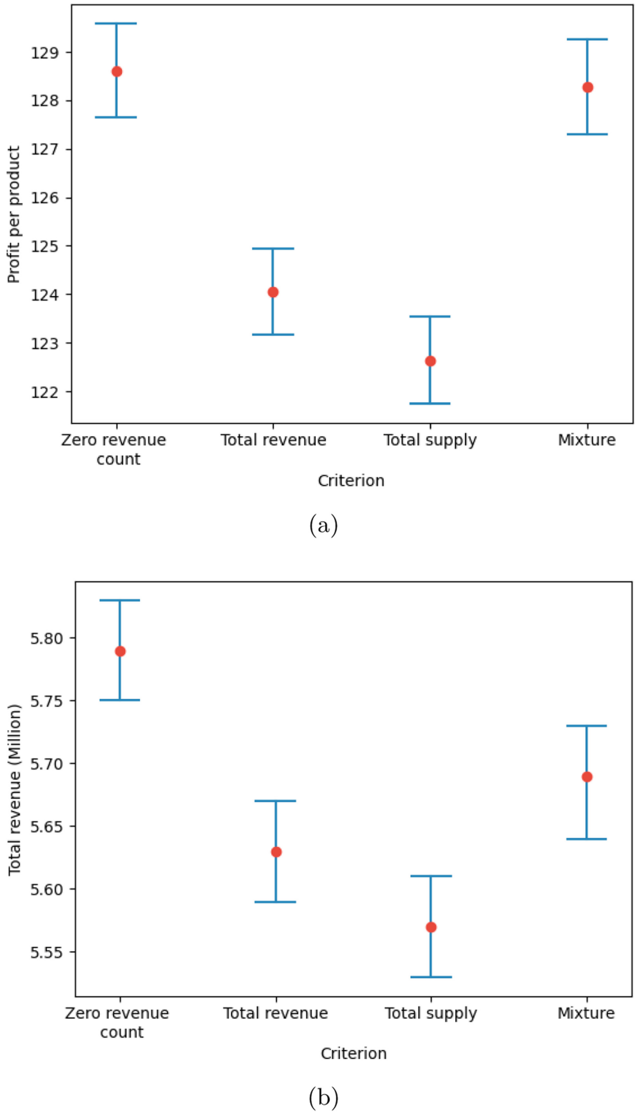

Fig. 4. 95% confidence intervals of (a) total revenue and (b) profit per product for all criteria included in pricing strategy.

to undergo a validation process, and further research is necessary to assess its reliability and effectiveness for real-world applications. While our initial findings appear promising, it is imperative to conduct additional testing and refinement to establish its potential for practical implementation. Future work will involve rigorous experimentation and simulation under diverse conditions and scenarios to assess the robustness of the approach, and to explore its benefits and limitations using historical data of the pharmaceutical parallel trade market.

Our agent-based model provides a framework to explore pricing strategies and optimize behaviors considering specific goals. In our future research, we aim to extend this model further to investigate the impact of other factors, such as the expiry date of available products, expected competitor's actions, type of behavior considering the product, development in purchase prices, and supply chain dynamics. Overall, our study highlights the importance of using data-driven approaches to understand and optimize behavior in complex markets such as the pharmaceutical industry.

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