A study on the Empirical Analysis of Collusive Behaviors in Pricing Strategies in the Digital Economy

Abstract

Keywords：Algorithmic Pricing、Tacit Collusion、Pricing Behavior、Deep Q-learning

This study delves into the emerging field of algorithmic pricing and its impact on collusion, addressing both academic and practical issues. Focusing on the digital retail market, our goal is to understand relationship between the decision-making of online e-commerce to adopt algorithmic pricing and the potential collusive behavior. We integrate the theoretical and empirical literature on algorithmic pricing, incorporate simulation results, and use web scraping to obtain machine learning data. The integration of these elements has led to the development of preliminary screening tools targeting businesses involved in algorithmic collusion, particularly online retailers. Our literature review explores the link between algorithmic pricing and tacit collusion, examining sellers' adoption of algorithmic pricing methods, their correlation with market prices, and the types of algorithms used. We then collect product prices from domestic online retailers, examine the use of algorithmic pricing, and simulate market price changes. Furthermore, using real market data and deep Q-learning, we simulate price trends under algorithmic pricing within market structures, providing valuable insights into the relationship between algorithmic pricing and collaborative behavior and providing practical recommendations to competition law authorities.

In our literature review, we analyze both domestic and international academic and practical cases, focusing on the joint behavior of non-algorithmic and algorithmic pricing strategies. We divide the literature into a theoretical part

and an empirical part. The theoretical part briefly introduces the relationship between price leadership games, game theory, and tacit collusion. We draw on Green et al.'s (2014) framework to explain the role of communication in tacit collusion and the conditions necessary to realize it in game theory. The empirical part selects 15 papers on tacit collusion published since 2014, categorizes them by industry and collusion mechanism, and introduces three court cases related to tacit collusion. Similarly, the literature review on algorithmic pricing and tacit collusion is also divided into two categories：one uses empirical methods to test the correlation between algorithmic pricing and market prices as an indicator of tacit collusion, and the other uses simulations to explore how algorithmic pricing achieves tacit collusion. The former also identifies patterns in algorithm usage and price changes, as well as the main patterns of product price changes under the algorithm.

Despite the importance of this research topic, the scarcity and difficulty of obtaining the necessary data limits the availability of empirical literature on algorithmic pricing. It is clear from these studies that there is currently no direct evidence of whether sellers use algorithms. Instead, the literature often relies on criteria such as (1) the frequency of price changes within a certain period, (2) the correlation between the seller's price and other prices, and (3) the response time of competitors to determine the suspicion of sellers using algorithmic pricing. Once confirmed, studies related to products priced using algorithms also identified five patterns of price changes among algorithmic sellers.

The summary of the recent experimental literature on algorithmic pricing includes seven studies. Due to the complexity and time-consuming nature of simulation algorithms, most experimental studies choose relatively simple configurations. These studies find that when there are fewer firms in the market, the likelihood of firms using algorithmic pricing to achieve tacit collusion is higher. However, even if there is an algorithm in the market, it cannot be directly concluded that prices will tend to preset collusion. Furthermore, algorithmic pricing may cause prices to fall, in addition to raising prices. Unlike

the price change model used by Maskin and Tirole (1988) to punish defection, the price reset effect results in a shorter low-price period in which both retailers simultaneously adopt algorithmic pricing.

We conduct a preliminary exploration of algorithmic pricing based on the prices of computer-related products and daily necessaries in Chinese Taipei. Overall, there is a possibility that retailers of selected computer-related products use algorithms to set prices. However, the frequency of price changes of the selected goods is at most about 2-3 times a day, contrasting with the high-frequency variations found in European and American literature. Therefore, it may be more appropriate to infer algorithmic pricing by observing the time required to respond to competitors' price changes. In addition, by observing price samples for one and a half years, we find that the pricing models of different products may undergo major adjustments in different periods. Therefore, a combination of manual and algorithmic pricing adjustment methods can be used.

In our simulations, we utilize real data and employ a more powerful deep Q-learning approach to simulate firm pricing behavior. In the two-firm scenario, we train the model to derive the demand curve for each firm during the training period. Subsequently, using deep Q-learning, we generate prices that simulate pricing behavior approaching collusion. However, there may be differences between simulated prices and actual price data. In other words, using algorithmic pricing without explicit agreement may still lead to tacit collusion. In a scenario where the market structure consists of one dominant firm and two smaller firms (three firms in total), simulated prices generated by deep Q-learning show that not all firms necessarily form collusive pricing when considering each other's decisions. Simulated prices are also affected by market structure. The experimental simulations are consistent with the literature, which shows that different models and scenario settings lead to different results, but there is a potential tendency toward collusion pricing.

This study provides the following policy recommendations：(1) For e-commerce platforms suspected of collusion, competition authorities can gradually collect relevant cost information and use public price data to analyze the pricing competition landscape. (2) Given that the same algorithm may produce different results under different circumstances, the regulation of algorithmic pricing should be handled on a case-by-case basis. In particular, algorithmic pricing, as an auxiliary tool for tacit collusion, cannot directly detect whether the pricing process is dominated by human agents. (3) If price fluctuations exhibit Edgeworth cycles, particularly when the duration of the trough is short, it may be related to algorithmic price resets. In such cases, caution should be exercised as price increases resulting from the Edgeworth Cycle may harm consumer benefits and economic efficiency. (4) The rapid development of algorithms may impact simulation results. The current simulation scenarios are relatively simple, and future research may discover more diversified outcomes of algorithmic pricing in more complex market situations. Relevant authorities should continue to explore these issues to gain a deeper understanding of competition issues and develop appropriate policy instruments.