JointCloud Resource Market Competition: A Game-Theoretic Approach

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***Abstract*— The current global economy is undergoing a transformative phase, emphasizing collaboration among multiple competing entities rather than monopolization. Economic globalization is accelerating the adoption of globalized cloud services, and in line with this trend, cloud 2.0 introduces the concept of "cloud cooperation". JointCloud, as a novel computing model for Cloud 2.0, advocates for the establishment of an evolving cloud ecosystem. However, a critical challenge arises due to the lack of direct incentives for a cloud to join the JointCloud ecosystem, leading to uncertainty regarding the rationale for the existence of the JointCloud ecosystem. To address this ambiguity, we draw inspiration from supply chain competition and formulate the market dynamics of resources within the JointCloud ecosystem. Our focus is particularly on the analysis of data resource trade within the JointCloud market. To comprehensively analyze the JointCloud market, we propose a market game that examines the competition among clouds within the ecosystem. We theoretically prove that a Nash Equilibrium always exists under the JointCloud market. Subsequently, we conduct an in-depth analysis of the profits of cloud resource manufacturers and cloud resource retailers as the number of clouds varies within the JointCloud ecosystem. Based on our analysis, we further explore the incentives for a cloud to participate in the JointCloud ecosystem. We then evaluate the performance of the proposed market game through extensive experiments, illustrating how process variables and profits change with the market size. The experiments demonstrate that the trends of various variables are aligned with our analysis obtained from the market game. Compared with the Cournot model, our proposed model captures the market power of both manufacturers and retailers, resulting in a model that closely mirrors real market dynamics. Our findings provide valuable insights into the cloud market within Cloud 2.0, offering guidance for stakeholders navigating the evolving landscape of cloud cooperation and competition.**

***Index Terms*— JointCloud, cloud computing, game theory, supply chain competition, resource management.**

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I. INTRODUCTION

WITH the deepening of economic globalization, the globalization of cloud services is expedited [1]. Under this trend, the cloud computing market is experiencing rapid development, with the value estimated to reach $550 billion by 2022 [2]. The increasing demand for cloud resources has given rise to several grand challenges. First, businesses relying on cloud services may require a burst of resources during specific events, such as, "World Cup Online Streaming" and "Apple Product Launch", exceeding the capacity of a single cloud provider. Second, under the trend of economic globalization, the globalized economy is experiencing a new evolution that advocates cooperation rather than monopolization. For example, The North American Free Trade(NAFTA) and the United States-Mexico-Canada Agreement(USMCA) facilitate trade among three North American countries; Sony and Ericsson formed a joint venture, Sony Ericsson, to develop and sell mobile phones. In response to this challenge, both academics and industry have embarked on the exploration of Cloud 2.0, aiming to meet the demands for cloud resources during such burst periods. Several concepts of Cloud 2.0 have been proposed. Researchers from Cornell and Europe have introduced "SuperCloud", designed to facilitate cross-cloud migration [3]. The University of Chicago advocates for "Sky Computing", with the goal of enabling cross-platform cloud services [4]. Cisco has proposed "Intercloud Fabric" to facilitate seamless communication across different cloud environments [5].

JointCloud [6], recognized as a pioneering cross-cloud cooperation architecture for cloud 2.0, facilitates integrated Internet service customization, advocating the concept of the JointCloud ecosystem. Diverging from the earlier Cloud 2.0 framework, JointCloud not only emphasizes the vertical integration of heterogeneous cloud resources but also focuses on the horizontal cooperation among multiple cloud resource providers. The primary goal of JointCloud is to create an evolving cloud ecosystem, wherein all participating cloud resource providers actively engage in deep collaboration with one another. This innovative approach offers cloud vendors an adaptable environment for flexible trading among themselves.

However, there is a lack of direct incentive for a cloud vendor to participate in the JointCloud environment. Firstly, from the perspective of large cloud resource providers. In nowadays' cloud market, the diverse buying habits of users make it challenging to establish customer relationships akin to Microsoft

Azure's successful guidance of Siemens Gamesa Renewable Energy through digital and cultural transformations. Consequently, major cloud providers often find themselves contending with a relatively fixed customer base. As the market matures, profits tend to stabilize. Therefore, there is no reason for large cloud resource providers to risk abandoning existing customers to join the JointCloud environment. On the other hand, small cloud resource providers encounter their own set of challenges in the JointCloud market. Compared to their larger counterparts, these players typically lack the brand recognition and infrastructure capabilities necessary to compete effectively. This compels them to compete aggressively on price and service quality to gain market share. However, this competitive landscape often leads to squeezed profit margins for smaller providers, making it challenging for them to achieve sustainable profitability. Thus, there is minimal incentive for small cloud resource providers to participate in the JointCloud environment.

To resolve this ambiguity, leveraging ideas from the concept of supply chain competition, we formulate a market model for resource markets within the JointCloud ecosystem. In the real-world cloud market, private clouds often face a shortage of cloud resources, leading them to procure cloud resources from large cloud vendors. This cloud resource trade aligns with the dynamics observed in the supply chain [9]. Accordingly, we model the cloud that sells cloud resources to other clouds as the manufacturer, the cloud that purchases cloud resources as the retailer, and the competition among clouds as supply chain competition [10].

For analyzing the JointCloud market, we expand upon the market game [11] introduced by Shapley and Shubik to examine the wholesale market dynamics within the JointCloud environment. In our game, each cloud is conceptualized as a rational game player that observes and reacts to the strategies of other clouds in a best-response manner [12]. We theoretically establish the existence of a Nash equilibrium, ensuring that no individual user will change their strategy unilaterally. Subsequently, we delve into a more detailed analysis of market behaviors under the Nash equilibrium. Our findings reveal that with an increase in the number of cloud resource manufacturers, the manufacturer's revenue decreases, while the cloud resource retailer's revenue sees an increase. Conversely, in scenarios where there are more cloud resource retailers in the JointCloud environment, the profit of a manufacturer increases, and the profit of a retailer increases when there are a sufficient number of manufacturers. Based on these market behaviors, we demonstrate the incentive for a cloud to join the JointCoud environment and systematically analyze the evolutionary process of the JointCloud ecosystem.

To analyze the effectiveness of our proposed method and the anticipated changes in the market, we conduct extensive experiments. The results demonstrate that the JointCloud market will converge to the Nash Equilibrium, and the trends in process variables and the profits of cloud resource manufacturers and retailers align with our analysis derived from the market game. Furthermore, we choose the Cournot model as a benchmark for our experiments. The results show that, in contrast to the Cournot model, our proposed model determines the wholesale price based on the decisions of both manufacturers and retailers and captures the influence wielded by both manufacturers and retailers. As a result, the wholesale prices derived from our proposed game exhibit more complex changing trends, with variations observed in response to fluctuations in the number of retailers. The interplay between manufacturers and retailers creates a dynamic pricing environment that is more reflective of real-world market conditions compared to the Cournot model. In summary, the contributions of this article are as follows.

- We construct a model that encapsulates the competition dynamics within the JointCloud ecosystem, drawing inspiration from concepts in supply chain competition. The proposed model is motivated by the dynamics of the real-world cloud market, where we conceptualize different clouds in the JointCloud environment as manufacturers and retailers. Our approach aligns with the intricacies of the actual world cloud market, wherein the wholesale price is determined based on both manufacturers' and retailers' decisions. The model effectively captures the competition inherent in the JointCloud market, offering a comprehensive modeling of the JointCloud ecosystem.
- We introduce a market game that encapsulates the decisions made by both cloud resource manufacturers and cloud resource retailers to analyze the JointCloud market. In this context, we explicitly consider data generated during the working process as a novel type of resource and analyze the potential profit associated with this data resource.
- We theoretically prove that a Nash Equilibrium consistently exists within the JointCloud ecosystem based on the proposed market game. We further analyze the market behavior under the Nash Equilibrium. Our findings indicate that an increase in the number of manufacturers and retailers in the JointCloud market correlates with an increase in the quality of resources. Specifically, the wholesale price experiences a decrease with an increase in the number of manufacturers and a decrease in the number of retailers. These results align cohesively with observed market trends.
- We analyze the motivation behind a cloud's decision to become part of the JointCloud environment based on the equilibrium market behavior. Furthermore, we undertake a comprehensive analysis of the evolutionary trajectory of the JointCloud ecosystem. Our findings reveal incentives for the cloud ecosystem, where all cloud providers could attain higher profits. We believe that the proposed market game and the model designed for the JointCloud environment offer an effective approach to dissecting the dynamics of the cloud market.

The rest of this paper is organized as follows. In section II, we discuss the related works of this article. In section III, we present the model for the JointCloud market. In section IV, we prove that a Nash equilibrium always exists. In section V, we derive the best function of the process variables and profit. In section VI, we analyze the market behavior under the Nash equilibrium. In section VII, we investigate market behavior when one market integrates into another. In section VIII, we analyze the incentive for the JointCloud ecosystem. Finally, in section IX, we conduct simulations to evaluate the JointCloud market.

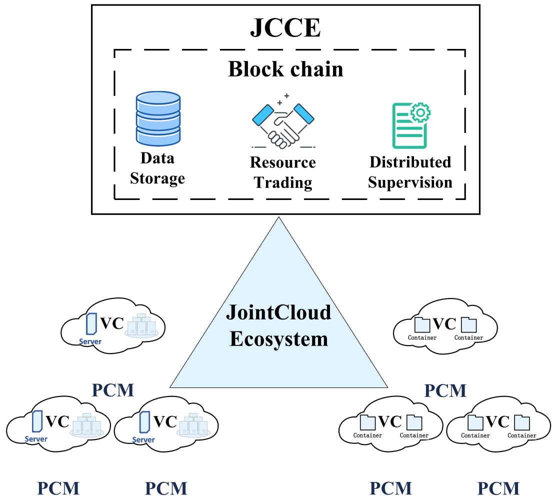


Fig. 1. JointCloud Architecture.

II. Related Works

A. Architecture of JointCloud

JointCloud is an innovative cloud computing model based on collaboration among diverse service entities and seamless integration of services from multiple clouds. This collaboration is facilitated through software definition, allowing users or other clouds to remotely access various cloud resources and service capacities [13]. In this way, clouds can collaborate in providing cloud services, and developers can utilize these services without the need to specify which cloud is providing the service.

The JointCloud architecture is illustrated in Figure 1. As depicted, JointCloud comprises two key components: the JointCloud Collaboration Environment(JCCE) and the Peer Collaboration Mechanism(PCM) [6]. Within JCCE, several BlockChain-based services [14] are integrated to address transaction-related issues, foster cloud cooperation, and evaluate cloud services. The implementation of PCM between clouds is crucial for effective collaboration based on JCCE. PCM includes all protocols during cloud collaboration [15]. Consequently, for a cloud seeking to join JointCloud, it is imperative to implement PCM as part of the integration process into the JointCloud environment [16].

When a consumer seeks the most cost-effective cloud resources within the JointCloud ecosystem. Clouds will initially transmit their quantities of cloud resources and corresponding prices to JCCE. It's noteworthy that these clouds may be virtual clouds, composed of multiple cloud vendors. Subsequently, the buyer selects a cloud resource provider and submits a request to rent cloud resources from the chosen provider. When the buyer wishes to transfer the task to a more cost-efficient cloud, the selected cloud sends a request to the cloud responsible for the task transfer. Upon receiving the request from the consumer, the clouds involved in the task restart the task.

B. Supply Chain Competition

In the realm of supply chain competition, as depicted in Figure 2, manufacturers compete by setting wholesale prices and determining the quality of resources, while retailers compete through their purchase budgets and the quantity of resources they acquire from manufacturers.

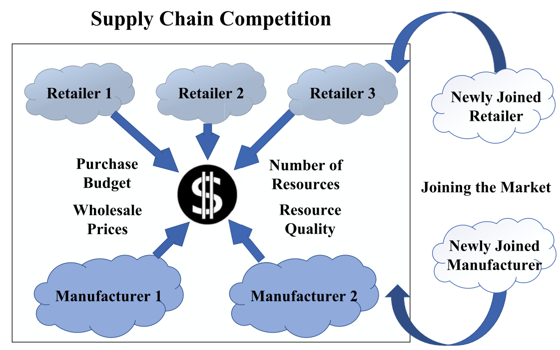


Fig. 2. Supply Chain Competition.

Existing literature mainly focused on several key areas. Firstly, some literature has concentrated on analyzing price competition between a single manufacturer and multiple retailers. Liu et al. [16] concentrate on scenarios where a single manufacturer competes with multiple retailers who adjust their prices in competition. Netessine and Zhang [17] establishes a non-linear price discount sharing contract, designed to coordinate the supply chain. Secondly, some literature focuses on the competition between multiple manufacturers and a single retailer. In this context, Adida et al. [18] consider the scenario with deterministic demand, where manufacturers competed by changing their price and production. Results indicate that horizontal competition among intermediaries encourages manufacturers to produce goods with smaller production capacities. Thirdly, some literature focuses on the scenario involving multiple manufacturers and multiple retailers. Adida and DeMigual [19] extend the work of Corbett and Karmarkar [20] by introducing a competition model that incorporates retailer risk aversion and price uncertainty. Their observation highlights that supply chain efficiency may significantly decrease with asymmetry in either manufacturers or retailers.

Finally, some literature concentrates on analyzing service and price competition within the supply chain. Recognizing the increasing significance of after-sale customer services and after-market support as pivotal sources of profit for manufacturers, the competition has been extensively discussed in academic literature. Sleptchenko et al. [21] concentrate on the market of repairable parts and the management of inventory system service. Feng et al. [22] investigate the services contract design and pricing. Wu et al. [23] and Bustinza et al. [24] explore the impact of the service capacity on both manufacturers' and retailers' profits.

However, there are two inherent problems with current supply chain competition models. Firstly, existing models fail to capture the impact of retailers on the wholesale price. Secondly, existing models overlook the significance of product differentiation among various cloud providers, particularly in the case of cloud resource retailers where this differentiation might be their sole market competitiveness. To address these limitations, we develop a competition model based on the market game that considers the influence of both manufacturers and retailers. Furthermore, our proposed model analyzes the potential profit arising from product differentiation, specifically data resources.

III. Modeling of the Joint Cloud Environment

In this section, we elucidate the rationale behind employing ideas from supply chain competition to model the JointCloud market. Furthermore, we introduce our model designed for the JointCloud market and introduced our proposed market game.

A. The Incentive for Utilizing Supply Chain Competition to Model the JointCloud Environment

In the real-world cloud market, It's common for heterogeneous cloud resource providers to engage in cooperation. For example, Weimeng Cloud collaborates with Wangyi Cloud for intelligent customer service operation management, and ByteDance integrates deeply with Amazon Cloud Technology [25] to jointly build a new generation of cloud data warehouse solutions.

Amidst this trend, some companies often opt to rent cloud resources from other cloud providers and deploy cloud services to the rented cloud resources. An illustrative example is TikTok, the short video-sharing app that has recently gained immense popularity. ByteDance, the parent company of TikTok, signed a three-year deal with Google in May 2019 to leverage Google Cloud's data storage services [26]. As part of the deal, TikTok agreed to pay at least 800 million dollars for the cloud services over this period. Similarly, Vodafone signed a six-year strategic partnership with Google to leverage data analytics to support the introduction of new products [27].

In the context of the cloud market, when a company lacks cloud resources, it frequently seeks resources from another company and benefits from the cloud services deployed on the rented cloud. This dynamic can be likened to the traditional supply chain where manufacturers sell products to retailers, who, in turn, sell them to consumers for mutual benefit. Drawing parallels between the product circulation process of the traditional supply chain and the cloud market, it is evident that the cloud market mirrors the dynamics of the traditional supply chain. In both scenarios, sellers profit by selling resources to buyers, while buyers benefit from utilizing the acquired resources. Motivated by these observations, we model the JointCloud market leveraging ideas from the concepts of supply chain.

Similar to the traditional supply chain, our model characterizes clouds selling cloud resources to other clouds as cloud resource manufacturers and those purchasing cloud resources as retailers. For instance, in the previously mentioned example, Google can be modeled as the manufacturer and TikTok as the retailer. However, there are some distinctions between the traditional supply chain and our model. Firstly, the prices of cloud resources exhibit significant fluctuations. For example, Azure announced price reductions of up to 60% for its virtual machines in 2019 [28]. Secondly, the number of manufacturers and retailers in the JointCloud market is highly dynamic. A cloud may act as a manufacturer when its cloud resources are abundant, and conversely, act as a retailer when facing shortages. This transformative relationship between manufacturer and retailer adds a unique dimension to the JointCloud market.

B. Modeling of JointCloud's Wholesale Market

As illustrated above, we categorize clouds selling resources to other clouds as manufacturers, and those vending resources to consumers as retailers [29]. Illustrated in Figure 2, We consider a group of manufacturers. We assume a manufacturer denoted by $s \in \{1, 2, \ldots, S\}$ offering cloud resources at a wholesale price ω. The cost incurred for provisioning the cloud resources is c [30]. Assuming that the manufacturer s sells o_s resources to a retailer, the profit for manufacturer s can be expressed as follows,

$$P_s = (\omega - c) \times o_s. \tag{1}$$

We assume that each retailer $r \in \{1, 2, \ldots, R\}$ procurers q_r resources and sells them to consumers at a unit price p_r. The demand function employed by retailers is assumed to have a linear inverse, a commonly used assumption in the analysis of the cloud market [20]. Specially,

$$q_r = A - d \times p_r. \tag{2}$$

where $A > c > 0$ and $d > 0$. The parameters A and d are related to the relationships between unit price and demand. A larger A indicates a lower influence of the unit price on demand, while a higher d indicates a greater influence of the unit price on demand.

Data resources, such as trained big data models and desensitized datasets, can be traded as valuable commodities. To enhance the quality of a model, it can be retrained using a consumer's private dataset to form a model that better meets the customized needs of consumers and improves the prediction accuracy of the model. In this scenario, we introduce the concept of the degree of data processing denoted as M_r, and the cost associated with processing data resources is represented as $RC(M_r)$. Based on [31], [32], and [33], we model the cost of data processing as a quadratic function of M_r,

$$RC(M_r) = e \times M_r^2 + f \times M_r \times M_j \times \ldots + g \times M_j \times \ldots \tag{3}$$

where e, f and g are constants determined by the resource provider. M_r and M_j represent the degree of data processing for different clouds.

We assume that a retailer will reprocess data resources after purchasing them from the manufacturer, and there is a linear relationship between the selling price and the processing level. Then each retailer's profit is,

$$p_r = (A + \zeta_r \times M_r - d \times q_r - \omega) \times q_r - RC(M_r) \times q_r. \tag{4}$$

where ζ_r is the profit factor of data processing, indicating how much profit data processing brings to the provider.

It is worth noting that our analysis is robust when considering other widely employed demand and profit functions.

In our model, each manufacturer s determines the quantity of resources o_s to be sold to the retailer. The total quantity sold to the retailer can be denoted as,

$$O = \sum_{s=1}^{S} o_s. \tag{5}$$

Conversely, each retailer r decides on his budget b_r without knowing the exact wholesale price. The total purchase budget is denoted as,

$$B = \sum_{r=1}^{R} b_r. \tag{6}$$

The wholesale price is typically defined as the cost per unit of a product that is sold to retailers. It is determined by dividing the total purchase budget by the total quantity of the product sold to the retailer,

$$\omega = \frac{B}{O} = \frac{\sum_{r=1}^{R} b_r}{\sum_{s=1}^{S} o_s}. \tag{7}$$

To simplify the subsequent proof, we denote the total purchase budget of all retailers, excluding retailer r as B_{-r}. Correspondingly, let O_{-s} represent the total quantity of resources sold by all manufacturers except manufacturer s. The quantity of resources a retailer can purchase is denoted as,

$$q_r = \frac{b_r}{\omega} = \frac{b_r}{B}O = \frac{b_r}{b_r + B{-}r}O. \tag{8}$$

According to the previous equation, q_r is a function of b_r. Thus, we can also rewrite budget b_r as a function of q_r,

$$b_r = \frac{q_r \times B_{-r}}{O - q_r}. \tag{9}$$

C. Market Game in JointCloud's Wholesale Market

To comprehensively analyze the JointCloud market, we design a two-stage game to model the behavior of the manufacturers and retailers.

Figure 3 illustrates the sequential process of the two-stage game. During the first phase of the two-stage game, each manufacturer determines the number of resources sold to the retailer, taking into account the impact of their actions on the wholesale price. In the second phase of the game, each retailer r determines his purchase budget b_r and the degree of data processing by estimating the wholesale price ω and the number of resources he can purchase q_r.

Starting from the second stage, each retailer aims at maximizing its profit,

$$\max_{b_r,\omega,q_r,M_r} \{(A{+}\zeta_r \times M_r{-}d \times q_r{-}\omega) \times q_r{-}RC(M_r) \times q_r\}. \tag{10}$$

Note that only b_r and M_r are freely decided by retailers, while the wholesale price ω and the quantity of resources q_r are constrained. However, due to the functional relationship between b_r and q_r, the retailer's optimization problem can be further translated into,

$$\max_{b_r,M_r} \left\{ \left(A + \zeta_r \times M_r - d\frac{b_r}{B}O{-}\frac{B}{O}\right)\frac{b_r}{B}O - RC(M_r) \times q_r \right\}. \tag{11}$$

In the first stage, the suppliers influence the wholesale price by determining the quantity of resources they intend to sell to the retailer. Each supplier endeavors to maximize its profit,

$$\max_{\omega,o_s} \{(\omega - c) \times o_s\},$$

$$s.t.\ \omega = \frac{B}{o_s + O_{-s}}. \tag{12}$$

As shown in Equation (12), each manufacturer anticipates in the JointCloud market by influencing the wholesale price ω endogenously.

Our proposed market game differs significantly from others in that we account for the impact of both manufacturers and retailers on the wholesale market. As analyzed above, within the proposed market game, the wholesale price is a result of decisions made by both manufacturers and retailers. A manufacturer possesses the ability to alter the wholesale price by adjusting the quantity sold to the retailer, while a retailer can influence the market through his decision on the purchase budget. In this way, the market game adeptly encapsulates the influence wielded by both manufacturers and retailers.

The primary reason for modeling the interactions among different cloud resource providers in terms of pricing and the quantity of resources is that these decisions most intuitively reflect the "power" of a game player. Poter [34] identifies buyer power, seller power, and new entrants as vital forces of competition. The Organization for Economic Co-operation and Development(OECD) [35] defines buyer power as how downstream firms can affect the terms of trade with upstream suppliers—in other words, a firm can cause the market price to change by selling more or less. Similarly, OECD defines seller power as the ability of a buyer to influence the terms and conditions on which it purchases goods —meaning a firm can influence the market by adjusting its purchase budget.

Our proposed market game captures the seller power and buyer power in the JointCloud market. Regarding new entrants, we analyze market behavior when new manufacturers or retailers join the JointCloud market, as detailed in the following sections.

Additionally, companies typically adopt one of three generic competitive strategies: "cost leadership", aiming to provide products or services at the lowest possible price; "differentiation", focusing on developing a significant aspect of a product to distinguish it from competitors; and "focus", a variation on the differentiation approach. Taking into that some small-scale cloud resource providers may choose the "differentiation" strategy, our proposed market game also considers the potential profit associated with data resources. We meticulously consider the customizable nature of data resources for customers and analyze the costs and profits linked to their customization. Our analysis pioneers the exploration of data resources and the associated profits, contributing to a more comprehensive understanding of the market dynamics.

IV. Nash Equilibrium of the JointCloud Market

In this section, we embark on a theoretical proof showcasing the existence of a Nash equilibrium within the JointCloud market. We prove that a Nash equilibrium exists for both the manufacturer and the retailer.

The Nash equilibrium stands as the pivotal solution for analyzing the outcomes of strategic interactions among multiple decision-markers. At the Nash equilibrium, traders converge to a point where they all maximize their profits. Consequently, the wholesale prices align with the traders' expectations,

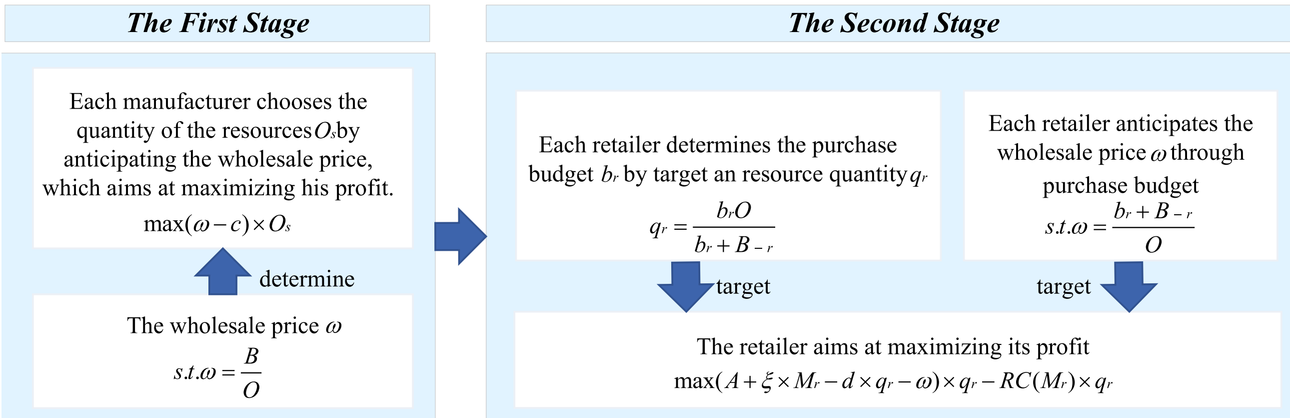


Fig. 3. Sequence of Decisions and Events in The Market Game.

factoring in any external influences that could affect these prices [36].

A. Nash Equilibrium of the Retailers

We first prove that there exists a Nash equilibrium for cloud resource retailers in the JointCloud market.

Lemma 1: Fudenberg and Tirole [37] establish that a pure-strategy Nash equilibrium is guaranteed to exist under two conditions (i) each manufacturer's action space forms a nonempty, compact and convex subset of Euclidian space [38], and (ii) the profit function of each manufacturer remains continuous and quasi-concave in their action space.

Theorem 1: Within the framework of the market game in the JointCloud market, a unique pure-strategy Nash equilibrium exists for retailers, and notably, this equilibrium is symmetric.

Proof: First, within the sub-game of retailers, each retailer's action space comprises the purchase budget b_r and the degree of data processing M_r. Evidently, the retailer's action space constitutes a nonempty and convex subset of the 2-dimensional positive real number space. Our task lies in providing the compactness of the action space.

For the degree of data processing, considering the finite data processing capacity inherent to cloud resource providers, an indisputable upper bound $\overline{M_r}$ exists. Consequently, the action space for the degree of data processing lies within the interval $[0, \overline{M_r}]$, forming a compact set.

For the purchase budget, to prove the compactness of the purchase budget's action space, we begin by taking the first derivative of the profit function,

$$\frac{\partial p_r}{\partial b_r} = \left(A + \zeta_r \times M_r - 2d\frac{b_r O}{B}\right)\frac{B_{-r}O}{B^2} - 1 - RC(M_r)\frac{B_{-r}O}{B^2}.$$

Intuitively, with an increase in the purchase budget, a retailer's profit should also rise; otherwise, raising the purchase becomes meaningless. Hence, the first derivative must be positive.

$$\left(A + \zeta \times M_r - 2d\frac{b_r O}{B}\right)\frac{B_{-r}O}{B^2} - 1 > 0.$$

After simplification, we obtain,

$$b_r < \frac{B \times \left[(A + \zeta \times M_r)B_{-r}O - B^2\right]}{2dO}.$$

As indicated in the above formula, there exists an upper bound $\overline{b_r}$ for the purchase budget. The action space of the purchase budget lies within the interval $[0, \overline{b}]$, constituting a compact set.

Based on the aforementioned proof, the retailer's action space constitutes a compact subset of 2-dimensional Euclidean space. The concavity of the profit function is verified by deriving its second derivative, as further detailed in the Appendix. Therefore, a pure-strategy Nash equilibrium exists within the sub-game of retailers. The proof of symmetric is established through the Kuhn-Tucker conditions for the retailers, which is presented in the Appendix. □

B. Nash Equilibrium of the Manufacturers

We then prove that there exists a Nash equilibrium for cloud resource manufacturers.

Theorem 2: Within the framework of the market game in the JointCloud market, a unique pure-strategy Nash equilibrium exists for manufacturers, and notably, this equilibrium is symmetric.

Proof: In the sub-game of manufacturers, each manufacturer's action space consists of the quantity of resources sold to the market o_s. The action space is a nonempty and convex subset of the 1-dimensional positive real number space. Thus, we only need to prove that the action space of manufacturers is a compact set. To begin, we examine the revenue of the manufacturer,

$$\frac{\omega o_s}{B} = \frac{o_s}{o_s + O_{-s}}.$$

Based on the previously stated formula, we derive that $\omega o_s < B$. As elucidated earlier, b_r and B are both bounded. Therefore, an upper bound $\overline{o_s}$ exists for the quantity of resources sold to the market. The manufacturer's action space is confined within the interval $[0, \overline{o_s}]$, representing a compact and convex subset of the one-dimensional Euclidean space.

As for the concavity of the profit function, we examine the second derivative of the manufacturer's profit with respect to o_s, which is,

$$\frac{\partial^2 p_s}{\partial^2 o_s} = -\frac{B}{(o_s + O_{-s})^2}.$$

The second derivative $\partial^2 p_s / \partial o_s^2 < 0$, indicates that the manufacturer's profit is concave with respect to o_s. The proof of symmetry is established through the Kuhn-Tucker conditions for the manufacturers, which are presented in the Appendix.

□

In summary, within the JointCloud market, both manufacturers and retailers exhibit a unique Nash equilibrium. Consequently, the JointCloud market as a whole possesses a unique Nash equilibrium.

V. The Optimal Decisions Under The Nash Equilibrium

In this section, we elucidate the equilibrium under the market game. We derive a closed-form expression for the optimal solutions pertaining to both cloud resource manufacturers and cloud resource retailers.

A. The Process Variables Under The Nash Equilibrium

We begin by characterizing the equilibrium wholesale price and quantity of resources that manufacturers sell to the retailers. To obtain the best response function for the degree of data processing, we calculate the first derivative of the retailer's profit with respect to the degree of data processing,

$$\frac{\partial p_r}{\partial M_r} = (\zeta_r - 2e \times M_r - f \times M_j \times \cdots) \times \frac{b_r O}{b_r + B_{-r}}. \tag{13}$$

Under the Nash equilibrium,

$$\frac{\partial p_r}{\partial M_i} = 0. \tag{14}$$

Subsequently, the best response function for the degree of data processing, $\hat{M}_r$ is characterized by the following condition,

$$2e\hat{M}_r + fM_r^{\hat{R}-1} = \zeta_r. \tag{15}$$

Similarly, under the Nash equilibrium, the optimal purchase budget b_r is determined by the following condition,

$$\frac{\partial p_r}{\partial b_r} = 0. \tag{16}$$

Given the symmetry of the Nash equilibrium, the purchase budget is subject to the following condition,

$$\begin{aligned}\frac{\partial p_r}{\partial b_r} &= \left(A + \zeta_r \times \hat{M}_r - 2d\frac{O}{R}\right)\frac{(R-1)O}{R^2 b_r} \\ &\quad - 1 - RC(\hat{M}_r)\frac{O}{R^2 b_r} = 0.\end{aligned} \tag{17}$$

Subsequently, we can derive the best response function for the purchase budget,

$$b_r = \left(A + \zeta_r \times \hat{M}_r - 2d\frac{O}{R}\right)\frac{R-1}{R^2}O - RC(\hat{M}_r)\frac{R-1}{R^2}O. \tag{18}$$

The total budget is $B = R \times b_r$,

$$B = \left[\left(A + \zeta_r \times \hat{M}_r - 2d\frac{O}{R}\right) - RC(\hat{M}_r)\right] \times \frac{R-1}{R}O. \tag{19}$$

The wholesale price can be represented as,

$$\begin{aligned}\omega &= \frac{B}{O}, \\ &= \left[\left(A + \zeta_r \times \hat{M}_r - 2d\frac{O}{R} - RC(\hat{M}_r)\right)\right]\frac{R-1}{R}.\end{aligned} \tag{20}$$

Then, the manufacturer's profit function can be reformulated as,

$$p_s = \left[A + \zeta_r \times \hat{M}_r - 2d\frac{O}{R} - RC(\hat{M}_r)\right] \times \frac{R-1}{R}o_s - c \times o_s. \tag{21}$$

To obtain the best response function for the number of resources sold to the market, we take the derivative of the retailer's profit with respect to the quantity,

$$\begin{aligned}\frac{\partial p_s}{\partial o_s} &= \left[A + \zeta_r \times \hat{M}_r - 2d\frac{O}{R} - RC(\hat{M}_r)\right]\frac{R-1}{R} \\ &\quad - 2d\frac{R-1}{R^2}o_s - c.\end{aligned} \tag{22}$$

Under the Nash equilibrium,

$$\frac{\partial p_s}{\partial o_s} = 0. \tag{23}$$

Then, we denote the number of resources sold to the market as,

$$o_s = \frac{R\left\{A + \zeta_r \times \hat{M}_r - RC(\hat{M}_r) - \frac{R}{R-1}c\right\}}{2d(S+1)}. \tag{24}$$

The total quantity of resources, denoted as $O = S \times o_s$, can be represented as,

$$O = \frac{S}{S+1}\frac{R}{2d}\left\{A + \zeta_r \times \hat{M}_r - RC(\hat{M}_r) - \frac{R}{R-1}c\right\}. \tag{25}$$

Under the Nash equilibrium, all resources offered by the manufacturers will be acquired simultaneously by the retailers. Given the symmetry inherent in the Nash equilibrium, each retailer will procure an identical quantity of resources,

$$q_r = \frac{O}{R} = \frac{S}{S+1}\frac{A + \zeta_r \times \hat{M}_r - RC(\hat{M}_r) - \frac{R}{R-1}c}{2d}. \tag{26}$$

With all decision variables related to the wholesale price have been denoted, we can denote the wholesale price as follows,

$$\begin{aligned}\omega &= R\frac{b_r}{O}, \\ &= \frac{R-1}{R}\left[A + \zeta_r \times \hat{M}_r - 2d\frac{S}{S+1}\right. \\ &\quad \left. \times \frac{A + \zeta_r \times \hat{M}_r - RC(\hat{M}_r) - \frac{R}{R-1}c}{2d} - RC(\hat{M}_r)\right].\end{aligned} \tag{27}$$

B. The Profits of Manufacturers and Retailers Under the Nash Equilibrium

Building on the results of the previous section, we derive a closed-form expression for the profits of manufacturers, retailers, and the entire JointCloud market. The profit of manufacturers is denoted as,

$$\begin{aligned} p_s &= (\omega - c) \times o_s, \\ &= \frac{R-1}{2d(S+1)^2}\Big[A + \zeta_r \times \hat{M}_r - RC(\hat{M}_r) - \frac{R}{R-1}c\Big]^2. \end{aligned} \tag{28}$$

The profit of retailers is represented as,

$$\begin{aligned} p_r &= (A + \zeta_r \times \hat{M}_r - d \times q_r - \omega) \times q_r, \\ &= \Big\{\frac{SR+2}{2(S+1)R}[A + \zeta_r \times \hat{M}_r - RC(\hat{M}_r)] \\ &\qquad - \frac{Sc(R-2)}{2(S+1)(R-1)}\Big\} \\ &\quad \times \frac{S}{S+1}\frac{A + \zeta_r \times \hat{M}_r - RC(\hat{M}_r) - \frac{R}{R-1}c}{2d}. \end{aligned} \tag{29}$$

Correspondingly, the profit of the entire JointCloud market is,

$$\begin{aligned} p_j &= S \times p_s + R \times p_r, \\ &= \frac{S}{2d(S+1)}\Big\{\big[A + \zeta_r \times \hat{M}_r - RC(\hat{M}_r)\big]R\Big\{\frac{SR+2}{2(S+1)R} \\ &\quad \times \big[A + \zeta_r \times \hat{M}_r - RC(\hat{M}_r)\big] - \frac{Sc(R-2)}{2(S+1)(R-1)}\Big\} \\ &\quad + \frac{R-1}{S+1}[A + \zeta_r \times \hat{M}_r - RC(\hat{M}_r) - \frac{R}{R-1}c]^2\Big\}. \end{aligned} \tag{30}$$

VI. Market Behavior Under the Nash Equilibrium

In this section, we analyze the market behavior under the Nash equilibrium, exploring the implications of JointCloud market expansion. Our analysis focuses on how the decisions of manufacturers and retailers evolve in response to changes in the number of clouds within the JointCloud market.

A. The Process Variables

We begin by analyzing how the process variables respond to the market expansion.

Theorem 3: As an increasing number of clouds engage in the JointCloud market as manufacturers, the equilibrium wholesale price is expected to decrease, accompanied by an increase in the quantity of resources sold to the retailers by manufacturers. Conversely, with more clouds participating in the JointCloud market as retailers, the equilibrium wholesale price is anticipated to rise, along with an increase in the quantity of resources sold to the market by manufacturers. The impact of the degree of data processing is primarily contingent on the profit and the cost functions associated with data processing.

Proof: To assess the impact of the newly joined manufacturers, we assume that the number of retailers in the JointCloud market remains constant. The first derivative of the quantity of resources sold by manufacturers concerning the number of the manufacturers is,

$$\frac{\partial q_r}{\partial S} = \frac{1}{(S+1)^2}\frac{A + \zeta_r \times M_r - RC(M_r) - \frac{R}{R-1}c}{2d}.$$

Intuitively, the quantity of resources sold to the retailers, q_r should always be positive,

$$\frac{A + \zeta_r \times M_r - RC(M_r) - \frac{R}{R-1}c}{2d} > 0.$$

Clearly, the aforementioned derivative is consistently positive, indicating that the quantity of resources sold to retailers will increase with the addition of more manufacturers to the JointCloud market. To analyze the impact of newly joined retailers, assuming the number of manufacturers remains constant, the first derivative of quantity concerning the number of retailers is,

$$\frac{\partial q_r}{\partial R} = \frac{S}{S+1}\frac{1}{(R-1)^2}\frac{c}{2d}.$$

The mentioned derivative consistently yields positive values, indicating that the quantity of resources will always increase with the addition of more retailers to the JointCloud market.

To analyze the market behavior of wholesale price, we adopt a similar approach by assuming the number of retailers remains constant and calculating the derivative of the wholesale price with respect to the number of manufacturers,

$$\frac{\partial \omega}{\partial S} = -\frac{1}{(S+1)^2} \times \frac{R-1}{R}\Big\{A + \zeta_r \times M_r - RC(M_r) - \frac{R}{R-1}c\Big\}.$$

As depicted in the above derivative, When multiple retailers(more than one) are involved in the JointCloud market, the derivative maintains a negative value. Consequently, the wholesale price experiences a decrease with the influx of additional manufacturers joining the market. To analyze the variation in the wholesale price concerning an increase in the number of retailers, we assume the number of manufacturers remains constant, the derivative of wholesale price with respect to the number of retailers can be denoted as,

$$\begin{aligned} \frac{\partial \omega}{\partial R} &= \Big(\frac{Sc}{S+1}\frac{1}{(R-1)^2}\Big)\frac{R-1}{R} + \\ &\quad \Big[A + \zeta_r \times M_r - RC(M_r) - \frac{R}{R-1}c\Big]\frac{1}{R^2}. \end{aligned}$$

In scenarios involving more than one retailer, the derivative is consistently positive. Consequently, as the market accommodates additional retailers, the wholesale price keeps increasing.

The unit profit that each retailer can acquire from processing data resources equates to the unit income derived from processing the data resources minus the unit cost. This can be represented as,

$$f(M_r) = \zeta_r \times M_r - RC(M_r).$$

For streamlining the subsequent proof, we rewrite the quantity of resourcesq_r and wholesale price ω as,

$$\begin{aligned} q_r &= \frac{S}{S+1}\frac{A + f(M_r) - \frac{R}{R-1}c}{2d}, \\ \omega &= \frac{R-1}{R}\Big[A + f(M_r) - 2d\frac{S}{S+1}\frac{A + f(M_r) - \frac{R}{R-1}c}{2d}\Big]. \end{aligned}$$

The influence of the degree of data processing can be encapsulated as follows,

$$\frac{\partial q_r}{\partial M_r} = \frac{\partial q_r}{\partial f(M_r)} \times \frac{\partial f(M_r)}{\partial M_r},$$

$$\frac{\partial \omega}{\partial M_r} = \frac{\partial \omega}{\partial f(M_r)} \times \frac{\partial f(M_r)}{\partial M_r}.$$

After adjusting the parameters,

$$\frac{\partial q_r}{\partial M_r} = \frac{S}{S+1}\frac{1}{4d^2}\Big[\zeta_r - RC(M_r)'\Big],$$
$$\frac{\partial \omega}{\partial M_r} = \frac{R-1}{R}\frac{1}{S+1}\Big[\zeta_r - RC(M_r)'\Big].$$

Based on the aforementioned derivative, the quantity of resources q_r and the wholesale price ω are contingent on the derivative of the cost function. □

Theorem 3 demonstrates that, under the Nash equilibrium, the entry of additional manufacturers into the JointCloud leads to a reduction in the wholesale price ω. This is intuitive, as heightened competition among manufacturers induces a lower wholesale price, reflecting the competitiveness within the JointCloud market. A lower wholesale price, in turn, mitigates the cost of purchasing cloud resources for retailers. Consequently, retailers may be more willing to increase their order quantity q_r.

In the scenario where more retailers enter the JointCloud market, the level of competition among them heightened, diminishing the bargaining power of each retailer. Consequently, retailers are more willing to pay higher prices due to the intensified competition. In response, each manufacturer is incentivized to supply more resources to the market, aiming to secure a larger share of the augmented budgets. The increase in b_r and O has two opposing effects on the wholesale price. Firstly, an increase in the purchase budget b_r leads to a higher wholesale price. Secondly, the wholesale price decreases as the quantity of resources supplied in the market increases. Evidently, the impact of the increase in the purchase budget is more significant than the effect of the increase in the quantity of resources supplied. Therefore, an increase in R results in a higher wholesale price ω.

The impact of the degree of data processing is primarily contingent on the derivative of the profit function associated with data processing. Although the profit of data processing may remain positive, the manufacturer may become unwilling to further increase their budget, as the cost of data processing rises faster than the profit derived from it. With an increase in the degree of data processing, each retailer increases their purchase budget to accommodate a higher degree of data processing. When the derivative is positive, the rise in the quantity of resources outweighs the increase in the wholesale price. Conversely, when the derivative is negative, the decrease in the wholesale price dominates the reduction in the quantity of resources.

B. The Profits of Manufacturers and Retailers

We further analyze the market behavior of the profits of manufacturers and retailers.

Theorem 4: As the JointCloud market expands to include more clouds as manufacturers, the profit of manufacturers is expected to decrease, while the profit of retailers is anticipated to increase. Conversely, with the expansion of the JointCloud market to involve more clouds as retailers, the profit of manufacturers is predicted to increase. Regarding the profit of retailers, for any given number of retailers, there always exists a threshold $\underline{S}$; when $S > \underline{S}$, the profit of retailers consistently increases. Moreover, the profit of the entire JointCloud market is projected to rise regardless of whether the market expands to include more manufacturers or retailers. The impact of data processing on profit primarily hinges on the profit and the cost functions associated with data processing.

Proof: To analyze the market behavior of the manufacturer's profit, assuming the number of retailers remains constant, we calculate the derivative of the profit of manufacturers with respect to the number of manufacturers S,

$$\frac{\partial p_s}{\partial S} = -\frac{R-1}{4d(S+1)^3} \times \big[A + \zeta_r \times M_r - RC(M_r) - \frac{R}{R-1}c\big]^2.$$

The aforementioned derivative is consistently negative. Therefore, the profit of a manufacturer is expected to decrease as the number of manufacturers in the market increases. To assess the impact of the number of retailers, assuming the number of manufacturers remains constant, we denote the derivative of the profit of manufacturers with respect to the number of retailers R as,

$$\frac{\partial p_s}{\partial R} = \frac{\big[A + \zeta_r \times M_r - RC(M_r) - \frac{R}{R-1}\big]^2}{2d(S+1)^2} + \frac{R-1}{d(S+1)^2}\big(A + \zeta_r \times M_r - RC(M_r) - \frac{R}{R-1}\big) \times \frac{c}{(R-1)^2}.$$

The above derivative is consistently positive; thus, the profit of manufacturers increases with the number of retailers. To analyze the market behavior of the retailer's profit, assuming the number of retailers remains constant, we take the derivative of the profit of retailers with respect to the number of manufacturers,

$$\frac{\partial p_r}{\partial S} = -2dq_r\frac{\partial q_r}{\partial S} + [A + \zeta_r M_r - RC(M_r) - \omega]\frac{\partial q_r}{\partial S} - q_r\frac{\partial \omega}{\partial S},$$
$$= \frac{A - 2d \times q_r + \zeta_r \times M_r - RC(M_r)}{R}\frac{\partial q_r}{\partial S} - q_r\frac{\partial \omega}{\partial S} > 0.$$

The third inequality follows from simplifying the wholesale price as $\omega = [A + \zeta_r \times M_r - 2dq_r - RC(M_r)](R-1)/R$. It's important to note that the wholesale price is always positive. Thus,

$$A + \zeta_r \times M_r - 2dq_r - RC(M_r) > \omega.$$

As illustrated above, $\partial q_r/\partial S > 0$, $\partial \omega/\partial S < 0$. Therefore,

$$\frac{\partial p_r}{\partial S} > 0.$$

To examine the impact of the newly joined retailers, we rewrite the profit of retailers in the form of a quadratic function of q_r,

$$p_r = -d \times q_r^2 + \big[A + \zeta_r \times M_r - RC(M_r) - \omega\big]q_r.$$

According to the properties of a quadratic function, when

$$q_r < \frac{A + \zeta_r \times M_r - RC(M_r) - \omega}{2d}.$$

As the quadratic function is a downward-opening quadratic function, When q_r satisfies the aforementioned equation, the profit of retailers will increase. However, when q_r exceeds the threshold, the profit of retailers will decreases.

Interestingly, when the market is sufficiently large, meaning both the number of manufacturers and retailers is sufficiently large, the profit exhibits a different trend. We start by analyzing the profit of retailers when the number of manufacturers approaches infinite, the profit of retailers can be simplified as,

$$\lim_{S\to+\infty} p_r = \Big(\frac{A+\zeta_r\times M_r - RC(M_r)}{2} - \frac{c(R-2)}{2(R-1)}\Big) \times \frac{A+\zeta_r\times M_r - RC(M_r) - \frac{R}{R-1}c}{2d}.$$

The derivative of the profit of retailers concerning the number of retailers is,

$$\frac{\partial \lim_{S\to+\infty} p_r}{\partial R} = \frac{c^2}{4d(R-1)^2}\frac{2}{R-1}.$$

The derivative is consistently positive; thus, when the number of manufacturers is sufficiently large, the profit of retailers will always increase.

To analyze the impact of the degree of data processing, we examine the profit of manufacturers concerning the degree of data processing,

$$\frac{\partial p_s}{\partial M_r} = \frac{R-1}{d(S+1)^2}\left[A+\zeta_r\times M_r - RC(M_r) - \frac{R}{R-1}C\right] \times \big(\zeta_r - RC(M_r)'\big).$$

According to the above derivative, the impact of data processing primarily depends on the derivative of the profit function and cost function. Similarly, we analyze the profit of retailers concerning the degree of data processing,

$$\begin{aligned}\frac{\partial p_r}{\partial M_r} &= (A+f(M_r)-\omega-2dq_r)\frac{\partial q_r}{\partial M_r} - q_r\frac{\partial \omega}{\partial M_r},\\ &= \frac{S}{2d(S+1)^2R}\times\Big[(R-2)\big[A+f(M_r)\big] + \frac{R}{R-1}(S+R-1)c\Big]\times\big[\zeta_r - RC(M_r)'\big].\end{aligned}$$

When $R>1$, whether the derivative is negative or positive mainly depends on the derivative of the profit function and cost function.

Finally, we analyze the profit of the entire JointCloud market. We rewrite the profit of the entire JointCloud market in the following form,

$$\begin{aligned}P_j &= R\times p_r + S\times p_s\\ &= R[A+\zeta\times M_r - d\times q - RC(M_r) - c]q\\ &= R\times\{-dq^2 + [A+\zeta\times M_r - RC(M_r) - c]q\}\end{aligned}$$

According to the properties of the quadratic function, when $q < A+\zeta\times M_r - RC(M_r) - c/2d$, the profit of the entire market keeps increasing. Considering the expression of q_r, it consistently satisfies the threshold, and q_r is increasing with the number of manufacturers. Consequently, the profit of the JointCloud market will invariably increase with the number of manufacturers. As for the impact of newly joined retailers, we calculate the derivative of the profit of the JointCloud market concerning the number of retailers,

$$\frac{\partial p_j}{\partial R} = S\frac{\partial p_s}{\partial R} + p_r + R\frac{\partial p_r}{\partial R}.$$

As indicated in the aforementioned derivative, when the market is sufficiently large, $\partial p_s/\partial R > 0$, $\partial p_r/\partial R > 0$, and obviously, $p_r > 0$. Thus, the profit of the entire JointCloud will increase as the number of retailers increases.

As for the impact of data processing, we calculate the derivative of the profit of the JointCloud market with respect to the degree of data processing.

$$\begin{aligned}\frac{\partial p_j}{\partial M_r} &= S\times\frac{\partial p_s}{\partial M_r} + R\times\frac{\partial p_r}{\partial M_r},\\ &= \Big\{S\frac{R-1}{d(S+1)^2}\Big[A+f(M_r) - \frac{R}{R-1}c\Big] + \frac{S}{2d(S+1)^2}\\ &\quad\times\Big[(R-2)(A+f(M_r)) + \frac{R}{R-1}(S+R-1)c\Big]\Big\}\\ &\quad\times\big[\zeta_r - RC(M_r)'\big].\end{aligned}$$

It is evident that the impact of the data processing depends on the profit function and the cost function of data processing. □

The escalating involvement of clouds acting as manufacturers unfolds in a sequence that impacts the profit dynamics, showcasing a trend where manufacturers experience diminishing profitability while retailers witness an enhancement in profits. This outcome is inherently logical, given that heightened competition among manufacturers tends to dilute individual profit margins, as a larger pool of players divides the overall benefits among themselves. Simultaneously, this intensified competition drives down wholesale prices, contributing to an increase in retailers' profits. From a market perspective, the escalation in retailers' profits outweighs the dip in manufacturers' profits. Consequently, the overall profitability within the JointCloud market demonstrates an upward trajectory as the number of manufacturers increases.

Having more clouds in the market as retailers have been identified as a catalyst for bolstering manufacturers' profitability. This surge is attributed to heightened resource demand stemming from an increasing retailer count, thus fostering greater potential profits for each manufacturer At first glance, one might assume that the profit of a retailer would dwindle with more clouds entering the JointCloud market as retailers. However, this dynamic shifts as the number of manufacturers grows substantially. In scenarios with a limited number of manufacturers, the profit of a retailer could indeed decline due to the diminished bargaining power. However, as the number of manufacturers increases, retailers may opt to escalate their purchase budgets, bolstering their influence as buyers. This strategic maneuver results in an upsurge in the wholesale price. The rising wholesale price, in turn, motivates manufacturers to increase their quantities of resources sold to the retailers, thereby positively influencing the profit of retailers. Notably, when the number of manufacturers hits a critical threshold, the positive impact derived from the increased availability of resources outweighs the negative repercussions of the rising wholesale prices. Consequently, retailers experience an upswing in profits as the number of retailers expands.

VII. Market Behavior Under Market Integration

In this section, we analyze the market behavior under market integration [39]. Currently, the cloud market in different regions operates independently, particularly within various cloud alliances. The progress in standard electronic business interfaces has significantly reduced transaction costs associated with utilizing resources from other cloud markets and has enabled cross-cloud market transactions. Under this situation, suppliers from each market engage in transactions with retailers from other markets, paving the way for the emergence of an integrated cloud market. For example, Google Cloud utilizes extensible markup language(XML) [40] to facilitate cloud storage management in a programmatic way.

We analyze the integration of two JointCloud markets, denoted as $JC-A$ and $JC-B$. $JC-A$ comprises R_A retailers ($R_A \geq 2$) and S_A manufacturers. Similarly, $JC-B$ comprises R_B retailers ($R_B \geq 2$) and S_B manufacturers. The integration of $JC-A$ and $JC-B$ results in an aggregate JointCloud market consisting of R retailers ($R = R_A + R_B$) and S manufacturers ($S = S_A + S_B$). We formally articulate the relationship between the pre-integration and post-integration profits in the ensuing theorem.

Theorem 5: As $JC-A$ and $JC-B$ consolidate into one JointCloud market, the total profit of firms in $JC-s(s \in A, B)$ experiences an increase if and only if,

$$R_s \times g(q(R,S,M_r)) + \Big\{(R-1)\times(A+f(M_r)) - \frac{R\times\{S\times[A+f(M_r)]-c\}}{S+1}\Big\} q(R,S,M_r)\Big(\frac{S_s}{S}-\frac{R_s}{R}\Big) \geq R_s \times g(q(R_s,S_s,M_{(r,s)})),$$

where

$$g(q) = (A+\zeta_r\times M_r - dq - RC(M_r) - c)q,$$
$$q(R,S) = \frac{S}{S+1}\times\frac{A+\zeta_r\times M_r - RC(M_r) - \frac{R}{R-1}c}{2\times d}.$$

Our theorem establishes a necessary and sufficient condition for each local supply chain to benefit from integration. On the right-hand side of the equation is the total profit of firms in $JC-s(S \in \{A,B\})$ before integration, where $g(q)$ represents each retailer's contribution to the market's profit. On the left-hand side is the total profit of firms in $JC-s$ after integration. The second part of the left-hand expression corresponds to the transfer of profits after integration. If the magnitude of this transfer of profits is sufficiently small, both markets benefit from integration.

We elucidate the rationale from the standpoint of $JC-A$, and a parallel explanation holds for $JC-B$. When $S_s/S > R_s/R$, signifying the dominant effect of integration is an expansion of markets for suppliers, the dynamics are characterized by an increased number of retailers from $JC-B$ becoming customers of suppliers in $JC-A$. In contrast, only a limited number of manufacturers from $JC-B$ enter as competitors. In this situation, the positive impact of newly integrated retailers outweighs the negative impact of manufacturers joining, resulting in an overall increase in the total profit of firms post-integration. Conversely, When $S_s/S < R_s/R$, indicating the dominant effect of integration as the expansion of markets for retailers. In this situation, the market share of each supplier sees a substantial decline. This occurs due to a significant influx of suppliers as competitors, with a relatively small number of retailers joining as customers. In this case, despite the newly integrated retailers increasing their order

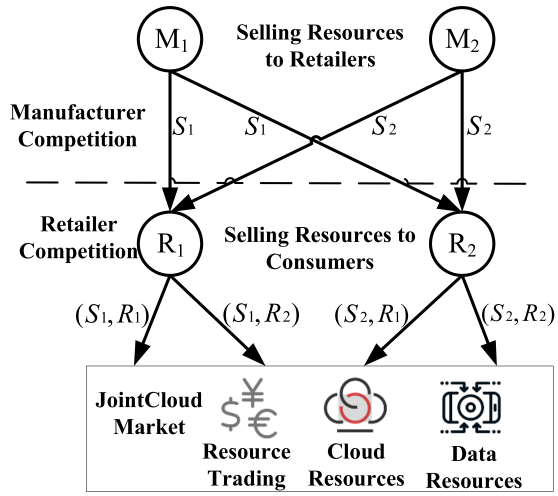


Fig. 4. The supply chain competition topology.

quantities, the positive effect is insufficient to counterbalance the negative effect of the decrease in market share for suppliers. Consequently, the total profit of firms experiences a decline after integration. However, when considering the entire market perspective, the profit reveals a different trajectory.

Theorem 6: The profit of the integrated market is greater than the sum of the total profits of local markets.

Our theorem demonstrates that even if integration induces a profit loss for one market, the profit gain in the other market always surpasses this loss. Consequently, the profit of the integrated market is always greater than the sum of the total profits of the local markets.

VIII. The Incentive for The JointCloud Ecosystem

In this section, we scrutinize the incentives within the JointCloud ecosystem and delve into an analysis of the evolutionary trajectory that the JointCloud ecosystem is likely to follow.

Although JointCloud offers a streamlined cross-cloud cooperation architecture for cloud resource providers, there exist several reasons why existing cloud vendors may hesitate to join the JointCloud market. Firstly, from the aspects of large-scale cloud resource providers, they often possess a well-established and relatively stable customer base. Joining JointCloud might not directly augment their revenue, leading them to prioritize the retention and stability of existing clientele. Secondly, from the aspects of small-scale cloud resource providers, they typically struggle to attract customers due to their limited resource offerings compared to larger counterparts. Consequently, joining the JointCloud market might not significantly benefit them. Thirdly, from the aspects of the cloud market, within the current cloud market landscape, stability prevails, with resource prices being reasonably established. There seems to be no compelling reason for JointCloud to redefine or readjust resource pricing, given the equilibrium and stability observed in the existing market.

Nevertheless, considering the market dynamics of the JointCloud market, our analysis focuses on the incentives that derive a cloud to become part of the JointCloud environment. In addressing the preceding three questions, we further investigate these incentives, examining them from three perspectives.

Firstly, considering the perspective of large-scale cloud resource providers, it is noteworthy that the current cloud market is predominantly dominated by a select few large-scale vendors who monopolize the industry, primarily deriving their profits from selling resources to consumers. Their revenue streams are characterized by a high degree of singularity. The introduction of the JointCloud environment provides these large-scale cloud vendors with a novel revenue stream. In this scenario, large-scale cloud vendors have the opportunity to function as manufacturers, selling their cloud resources to smaller cloud vendors. As elucidated in the above section, the profitability of manufacturers exhibits an upward trend with the entry of retailers into the market and, conversely, tends to decline with the entry of more manufacturers. Although the profit of an individual manufacturer might experience a decline with the entry of more manufacturers into the JointCloud environment, the overall number of manufacturers remains limited. With the number of manufacturers stable, the profits of these manufacturers will benefit from an increasing influx of retailers. In essence, for large-scale cloud vendors, the JointCloud environment offers a fresh source of income, diversifying their revenue streams and contributing to an overall increase in profitability.

Secondly, from the perspective of small-scale cloud resource providers, the current cloud market is characterized by the dominance of large-scale cloud vendors, leaving a relatively small space for participation by small cloud vendors. The introduction of the JointCloud environment emerges as a facilitator for cooperation among small cloud vendors, offering a convenient platform for resource trading. Within the JointCloud market, multiple small cloud vendors can collaborate to collectively compete against major cloud vendors, thereby expanding their share of the cloud market. Additionally, the JointCloud framework furnishes small-scale cloud resource providers with a secure environment environment for resource trading. In this situation, small-scale vendors have the option to function as retailers, avoiding direct competition with larger counterparts. A small-scale cloud resource provider can opt to procure cloud resources from large-scale cloud vendors, subsequently refining and offering highly customized resources to end-users. As we illustrated above, the profitability of retailers tends to increase with the entry of more manufacturers into the JointCloud environment. Furthermore, in a sufficiently large JointCloud market, the profits of retailers continue to grow with the influx of more retailers. This implies that the profits of small cloud vendors have the potential to increase even in the presence of heightened competition in the market. In summary, the JointCloud environment serves as an empowering platform for small-scale cloud resource providers, offering collaborative opportunities and a secure trading environment, ultimately leading to a consistent increase in profitability.

Thirdly, from the perspective of the JointCloud market. Under the trend of economic globalization, potentially competing entities are encouraged to collaborate to maximize profits and address the burgeoning demand for resources. However, the existing cloud market is presently monopolized by a limited number of large-scale cloud resource providers. The advent of JointCloud offers a solution to alleviate the monopolistic tendencies within the cloud market. Large-scale cloud resource providers can function as manufacturers, reaping benefits from selling large amounts of resources to small cloud resource providers. Concurrently, small cloud resource provider can engage in collaborative efforts, enhancing their market competitiveness. As illustrated above, the profitability of the entire JointCloud environment consistently increases with the integration of more clouds into the JointCloud. This dynamic fosters a robust and progressive cloud ecosystem, allowing cloud vendors of varying sizes to benefit from collaboration. In summary, JointCloud promotes a healthy and evolving cloud ecosystem where cloud vendors of different scales can derive increased profits through collaborative endeavors compared to operating independently.

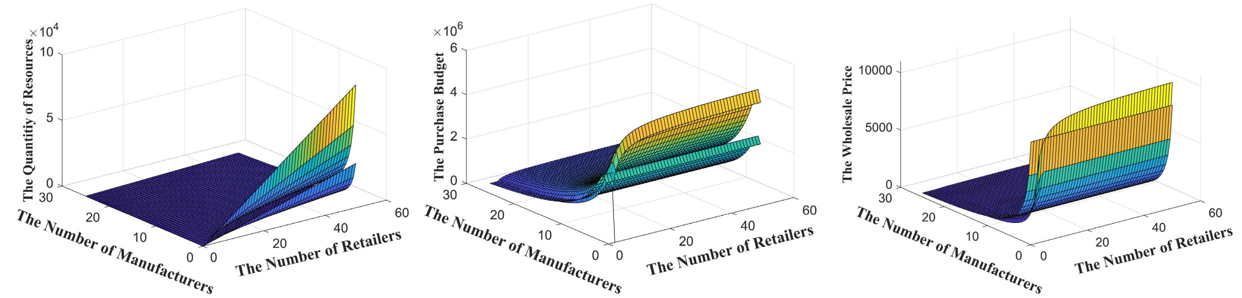
In this manner, we speculate on the evolution process of the JointCloud environment. In the initial stages of the JointCloud environment, large-scale cloud resource providers, who initially monopolized the market, enter the JointCloud market to explore a new income source. During this phase, their profits may not experience a significant increase, especially as the number of retailers grows at a relatively slow pace. Subsequently, the JointCloud environment attracts small cloud resource providers to participate, enticed by the availability of more affordable cloud resources offered by an increasing number of manufacturers. The growing presence of small cloud resource providers, in turn, serves as an impetus for larger cloud vendors to join the JointCloud, seeking access to a broader market. In this manner, the JointCloud progressively expands its reach to include a more extensive array of cloud resource providers, creating a dynamic ecosystem where collaboration among large and small vendors becomes pivotal to the evolution of the JointCloud environment. This cyclical process of attraction, participation, and expansion contributes to the ongoing development and enrichment of the JointCloud framework.

IX. Simulation Results

In this section, we conduct a series of numerical experiments to gain a comprehensive understanding of the market behavior within the JointCloud market. We aim to provide valuable insights into the dynamics of the JointCloud market and analyze market behaviors under the Nash equilibrium. The competition model [41] encompasses 2 manufacturers and 2 retailers, depicted in Figure 4. For the parameters, we specifically set $A = 900$, $d = 3$, $\zeta = 60$, $e = 1.5$, $f = 1$, and $g = 1$. These parameters are primarily inspired by [19], [20], [42], [43]. For the cost, we utilize the cost of providing a 4 cores, 16GB virtual machine, which we believe is a commonly used configuration, and set $c = 5$. The maximum number of manufacturers is set to 25 and the maximum number of retailers is set to 50. This setting is based on a 2023 Google survey, which identified 14 of the most used cloud resource providers. However, we believe this number may be an underestimation, as many local providers might have been overlooked. Therefore, we extend the number of manufacturers to 25. For the number of retailers, we set the count to be twice the number of manufacturers, as this ratio is sufficient to demonstrate the trend of different variables. Additionally, we introduce the Cournot model [44] as a benchmark and then present our proposed market game.

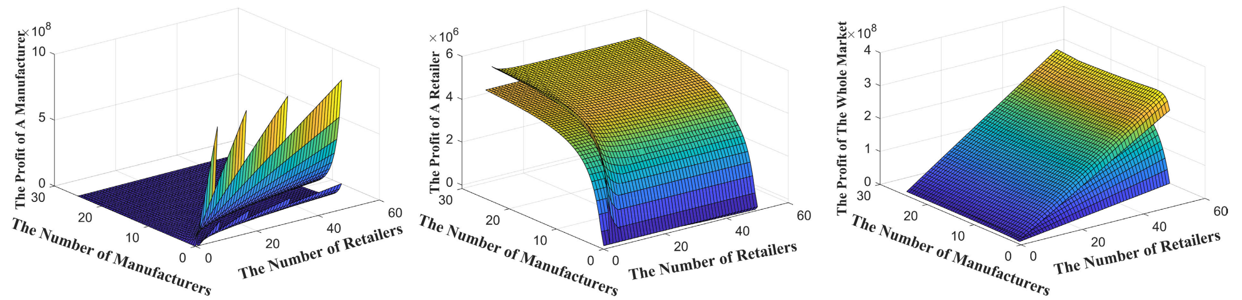
A. The Process Variables Under The Nash Equilibrium

To analyze the market behavior under the Nash equilibrium, we make the assumption that the number of manufacturers or



(a) The Quantity of Resources that A Manufacturer sold to the Market (b) The Purchase Budget of a Retailer (c) The Wholesale Price

Fig. 5. Process Variables of The Market Game.



(a) The Profit of A Manufacturer (b) The Profit of A Retailer (c) The Profit of The Whole Market

Fig. 6. The Profit of the Market Game.

retailers remains constant. We analyze the market behavior when a new cloud resource provider enters the JointCloud environment, either as a manufacturer or a retailer.

Figure 5(a) illustrates the quantity of resources a manufacturer aims to sell to retailers q_r. As shown, when the number of retailers is 0, regardless of the number of manufacturers in the JointCloud market, the quantity of resources is 0, as there is no demand for resources, and manufacturers cannot generate any profit from selling cloud resources. However, as more small-scale cloud resource providers join the JointCloud environment as retailers, the demand for cloud resources increases, enabling manufacturers to profit from selling resources to retailers.

Figure 5(b) depicts the purchase budget of a retailer. The purchase budget of a retailer increases with the entry of more retailers into the JointCloud market and decreases with the entry of more manufacturers. The heightened competition among retailers leads to an increase in the budget, as each retailer elevates its budget to secure a larger share of resources. Conversely, the competition among manufacturers has a diminishing effect on the budget, as each manufacturer reduces its wholesale price to attract more retailers. The results show the dual impact of market forces, where retailer competition amplifies budgetary allocations, while manufacturer competition exerts a downward pressure on budgets.

Figure 5(c) presents the wholesale price ω, which is determined by both the purchase budget and the quantity of resources that manufacturers sell to retailers. As illustrated in Figure 5(a) and Figure 5(b), both the purchase budget and the quantity of resources increase with a greater number of retailers and decrease with a greater number of manufacturers. Apparently, Figure 5(c) indicates that changes in the purchase budget have a more dominant effect than changes in the quantity of resources. Upon comparing Figure 5(b) and Figure 5(c), it is apparent that the trend of the wholesale price closely mirrors the trend of the purchase budget. This alignment in trends can be attributed to the fact that changes in the budget exert a more significant impact on the wholesale price.

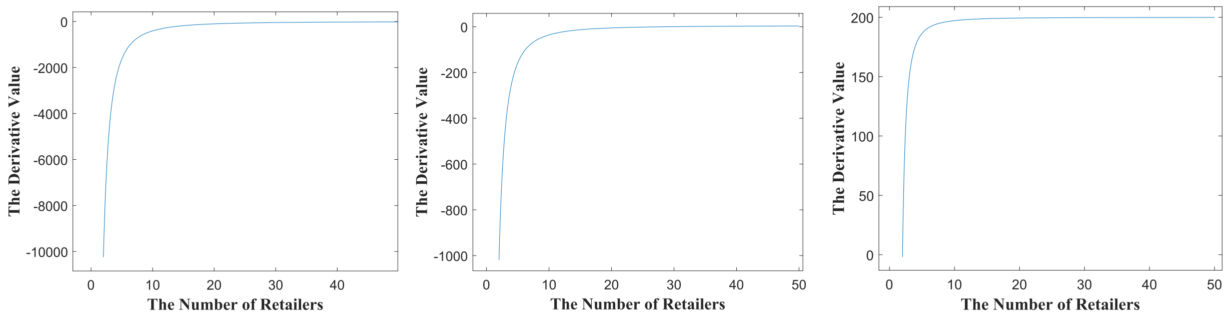
Comparing our proposed market game with the Cournot game, as illustrated in Figure 5(a), 5(b), and 5(c), notable distinctions emerge. Specifically, the quantity of resources sold to retailers in the Cournot model is observed to be smaller than that in the market game. This discrepancy arises because the Cournot game overlooks the impact of increasing retailers and fails to account for the growing demand in the market. As for the purchase budget and the wholesale price, the Cournot game neglects the buyer power. Consequently, both the budget and wholesale price remain unaltered with changes in the number of retailers. In contrast, our proposed market game reflects retailers' buyer power, resulting in a more nuanced and dynamic set of changing trends.

B. The Profits of Manufacturers and Retailers

Figure 6(a) depicts the profit of a manufacturer, the profit of a manufacturer experiences a rapid ascent with the growing number of retailers, particularly noticeable when the number of manufacturers is limited. This surge can be attributed to the escalating demand for cloud resources stemming from newly onboarded retailers. Especially in scenarios with a small number of manufacturers, a larger proportion of the heightened demand is allocated to each manufacturer.

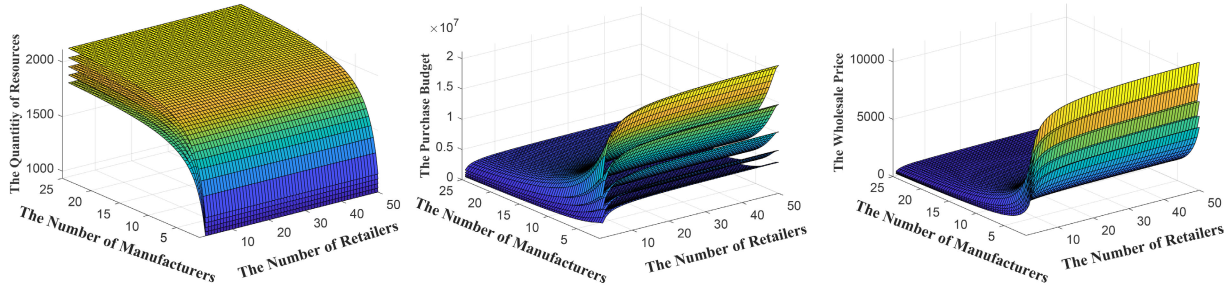
The trend observed in the profit of a manufacturer closely mirrors that of the quantity of resources a manufacturer sells to retailers. As previously analyzed, a manufacturer's profit hinges on both the quantity of resources sold and the wholesale price. The former holds a more significant influence over the latter. Consequently, the uptrend of the profit of a manufacturer aligns closely with the quantity of resources sold to the market.

In Figure 6(b), the retailer's profit showcases an increase with a rising count for manufacturers, yet experiences a decline



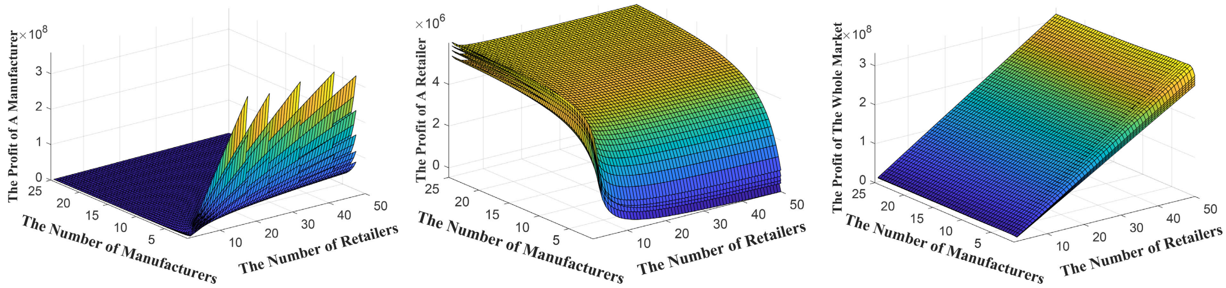
(a) The Derivative When S=50 (b) The Derivative When S=500 (c) The Derivative When S=5000

Fig. 7. The Derivative of The Profit of A Retailer with Respect to The Number of Retailers.



(a) The Quantity of Resources that A Manufacturer sold to the Market (b) The Purchase Budget of a Retailer (c) The Wholesale Price

Fig. 8. Process Variables of The Market Game with different profit of data processing.



(a) The Profit of A Manufacturer (b) The Profit of A Retailer (c) The Profit of The Whole JointCloud Market

Fig. 9. The Profit of the Market Game with different profit of data processing.

when the number of retailers falls below 44. As previously heightened, a retailer's profit primarily hinges on the quantity of resources purchased from manufacturers and the wholesale price. The surge in the retailer's profit with a greater number of manufacturers can be attributed to the effect of lower wholesale prices. As for the impact of newly onboarded retailers, in scenarios with a limited number of manufacturers, the adverse effect of wholesale price might be more pronounced. However, with a sufficiently large count of manufacturers, the amplified resource quantity holds more weight, consequently bolstering the retailer's profit with the increasing retailer count.

To pinpoint the juncture at which the retailer's profit initiates an increase, we examine the derivative of the retailer's profit concerning varying numbers of manufacturers. A Comparison among Figure 7(a), Figure 7(b), and Figure 7(c) reveals that with an increase in the number of manufacturers, the turning point becomes smaller. For example, When $S = 50$, the derivative is always negative. In contrast, with $S = 500$, the derivative reaches 0 at $R = 41$, and notably, the derivative consistently maintains positivity with $S = 5000$.

Figure 6(c) shows the profit of the entire JointCloud market consistently rises with the increasing number of manufacturers and retailers. There is a notable acceleration in the market's profit when the number of manufacturers elevates from 0 to 1, underscoring the significant influence and importance attributed to manufacturers within this market framework.

As depicted in Figure 6(a), the profit of a manufacturer under the Cournot game follows a similar trend to the quantity of resources, resulting in smaller profits due to a lower quantity of resources. Regarding the profit of a retailer, illustrated in Figure 6(b), the Cournot game overlooks the buyer power of a retailer, leading to a scenario where the profit of a retailer remains unchanged with the number of retailers. In contrast, our proposed market game aligns more closely with the actual market. In terms of the profit of the entire market, depicted in Figure 6(c), the Cournot game exhibits significant changes as the number of manufacturers increases but changes slowly with the increase in retailers. Neglecting the buyer power of retailers in the Cournot game gives manufacturers greater influence. In comparison, our proposed market game considers the impact of retailers' buyer power, resulting in a more stable trend that better aligns with the real market.

C. The Impact of Data Processing

The impact of data processing primarily hinges on the unit profit derived from this process. To illustrate the impact of data processing, we've assigned values of 1, 5, 10, 500, and 1000 to represent the unit profit garnered from data processing, expressed as $(f(r_i) = 1, 5, 10, 500, 1000)$.

We first depict the process variables under varying unit profits derived from data processing. The pivotal impact of data processing is notably contingent on the incremental rise in the unit profit yielded from this process. As depicted in Figure 8(a), Figure 8(b), and Figure 8(c), with an escalation in the unit profit from data processing, significant changes are observed: the highest quantity of resources ascends from 1548 to 2257. Correspondingly, the peak wholesale price climbs from 2327 to 9123, and the highest purchase budget escalates from 5.6×10^6 to 1.6×10^7. This phenomenon is attributed to the increased profitability of data processing. Retailers, incentivized by this profit, demonstrate a willingness to augment their purchase budgets, aiming to acquire more resources from manufacturers. Consequently, the quantity of resources manufacturers experience an upsurge. Simultaneously, the escalation in purchase budgets triggers an increase in the wholesale price.

As illustrated in Figure 9(a) and Figure 9(b), the impact of $f(r_i)$ rising from 5 to 10 is evident across the profit of a manufacturer, a retailer, and the entire JointCloud market. The manufacturer's profit climbs from 5.1×10^7 to 1.4×10^8, while the retailer's profit rises from 5.5×10^6 to 6.2×10^6. By witnessing an upswing in both the quantity of resources and wholesale prices, manufacturers derive benefits from data processing. Concurrently, retailers benefit from increasing requests for high-quality resources. Overall, the JointCloud market reaps substantial gains from increased resource requests and elevated wholesale prices.

X. Conclusion

In this paper, considering the interactions among different cloud resource providers, we model the JointCloud market drawing inspiration from supply chain competition. To analyze the JointCloud market, we develop a comprehensive market game that encompasses the decisions undertaken by both cloud resource manufacturers and retailers. Through theoretical analysis, We establish that a Nash equilibrium always exists within the JointCloud market. Subsequently, we analyze the market behavior under the Nash equilibrium. Based on the market behavior, we explore the rationale behind a cloud's inclination to join the JointCloud, shedding light on the incentives and underlying reasons that drive cloud entities towards participation in this innovative ecosystem.

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