The Competition between Public and Hybrid Cloud Providers

Research-in-Progress

Yijiang Liu **Shengli Li**

Yinghong Wan

Abstract

In this research, we present a game-theoretical model to analyze the competition between a public cloud provider and a hybrid cloud provider, considering their differences in deployments and pricing models. We first find that the clients with more data to process are more apt to choose the hybrid cloud provider. We then find that when the public cloud product and hybrid cloud product are sufficiently differentiated, the public cloud provider can command a monopoly price; however, when they are not highly differentiated, the market competition will be intensified. Further, we find that the hybrid cloud provider is always willing to charge a low price for its public cloud service to attract clients.

Keywords: Cloud computing, hybrid cloud, public cloud, cloud computing competition

Introduction

Cloud computing allows clients to store and process data in either privately owned cloud, or an externally-hosted cloud server. Public cloud is one popular type of cloud computing services and has caught up with the industries. Public cloud providers, such as AWS (Amazon), Azure (Microsoft), Alibaba Cloud (Alibaba Group), and Google Cloud Platform (Google), offer standard services to clients to store and process data in their own cloud platform. When adopting a public cloud, clients are no longer concerned about investment in IT infrastructure and demand uncertainty since they pay cloud providers according to the amount of services that they use. However, due to the external-host feature of public cloud services, data security has become a major concern for their clients. For example, the breakdown of AWS on March 1, 2017 affected many clients' daily operations, such as Yahoo! Mail and Trello. In addition, lack of customization of public cloud services is also a significant issue for clients, since standard cloud services may not suit their business requirements.

To address these issues, many cloud providers, such as Oracle, VMware, HP, and IBM, offer private cloud products. Private cloud providers offer customized cloud products to clients and help clients to deploy their private cloud locally. Having data stored and processed locally addresses the issue of data security. However, despite its advantages in both customization and security, private cloud service has

* Corresponding Author.

faced criticism; clients still have to "purchase and manage" and cannot deal efficiently with demand uncertainty due to the limited capacity of private cloud storage.

Hybrid cloud services are another type of cloud computing product. Hybrid cloud is built based on a private cloud model, but also has some of the advantages of public cloud. Using a hybrid cloud, the clients first need to build a private cloud and process data locally. When the real-time data requirement exceeds the capacity of the private cloud component, clients then submit the overflowing data to the public cloud component. By using the hybrid cloud, clients can handle the issue of demand uncertainty while also enjoying the benefits of customization and security. As a result, hybrid cloud solutions have become the priority choice for many clients seeking cloud computing solutions. According to Rightscale, in 2018, 51% enterprises chose the hybrid cloud as their cloud computing strategy.[1]

In this paper, we focus on the competition between a public cloud provider and a hybrid cloud provider. Besides the difference in their deployments, the modes of payment are also different between public and hybrid cloud service providers; public cloud providers typically adopt a "pay as you go" pricing model, which allows clients to pay according to the amount of services they have used. Hybrid cloud providers, on the other hand, charges both a fixed fee and a variable fee. The fixed fee is the up-front one-time fee which the clients need to pay for the hybrid cloud solution. The variable fee, which is referred to as the hybrid cloud price, is charged based on the "pay as you go" pricing model, when the clients use the public cloud to deal with the overflowing transactions. Capturing the essential differences in their respective deployments and pricing models, we aim to address the following research questions:

How is the market segmented when there exists a public cloud provider and a hybrid cloud provider?

What are the optimal competitive strategies for each provider?

First, we show analytically that clients with more transactions to process prefer the hybrid cloud. Second, we find that when the public cloud product and the hybrid cloud product are sufficiently differentiated, the public cloud provider charges a monopoly price. When they are not highly differentiated, the competition between two providers will be intensified. Finally, whether or not there exists a public cloud competitor, the hybrid cloud provider is willing to offer the public cloud service with a low price to attract the clients to use the hybrid cloud.

Literature review

Our work draws on two lines of literature: studies of selling and renting, and economic analysis of cloud computing.

In the area of selling and renting, many studies have used a single firm as the setting. Varian (2000) identified some circumstances in which a single content provider can obtain more profits from pay-per-use pricing. Sundararajan (2004) compared the profit of selling and renting for an information goods provider under circumstances of incomplete information. Shin-yi and Banker (2010) examined the profit of fixed fee pricing, pure usage-based pricing, and two-part tariff pricing for a monopolist providing information services. Additionally, some scholars have studied selling and renting in the setting of a competitive market. Fishburn and Odlyzko (1999) compared renting and selling in a competitive market where two providers offered the same electronic goods with different pricing methods. Choudhary (2010) studied selling and renting in a duopoly information goods market, finding that adopting asymmetric pricing schemes can be a Nash equilibrium for information goods. In essence, public service providers adopt the renting pricing model while hybrid cloud adopts a mix of the selling and renting models.

Our research is also related to the body of literature on cloud computing. Numerous studies have recently investigated various topics related to cloud computing, such as revenue and risk management, security assurance, upgrading and maintenance, and others. (Ali et al. 2015; August et al. 2014; Choudhary and Zhang 2015; Giessmann and Legner 2016; Schneider and Sunyaev 2016). In our study, we mainly concentrate on the competition in the cloud computing market. Ma and Kauffman (2014)

[1] http://www.new-finance.cn/list/26/5126.html

studied the competition between two SaaS providers. Ma and Seidmann (2015) investigated the competition between an SaaS provider and modifiable off- the-shelf (MOTS) software provider. Guo and Ma (2018) studied the competition between a perpetual software and software as a service. In the terms of the competition between cloud providers, Liu et al. (2015) studied the client-side security level as well as cloud computing price in a competitive cloud market. Feng et al. (2018) explored the quality, pricing, and release time of two SaaS providers. Few papers focused on the competition of different forms of cloud computing. In this paper, we investigate the competition of cloud computing providers who offer different forms of cloud services, which, to our best knowledge, hasn't been studied.

Model

In this section we outline the fundamentals of our model. Assume there are two firms in the market. Firm 1 is a public cloud provider who offers public cloud services to clients with unit price p_c, which is referred to as the public price, and the unit value v_c. Firm 2 is a hybrid cloud provider. It first offers private cloud solution with one-time up-front fixed fee f. Meanwhile, it also offers public cloud service for clients who have purchased the private cloud with unit price p_h, which is also referred to as the hybrid cloud price. The unit value for the hybrid cloud is v_t. Due to the customization of the hybrid cloud, the utility of hybrid cloud service is higher than that of public cloud service, that is, $v_c < v_t$. Meanwhile, we assume the cost of developing public and hybrid cloud products has sunk so that it no longer affects firms' strategies.

In the market, the clients have two different features. First, they have different data processing needs, measured by different expected data volumes; some clients have more than others. Second, each client's actual data volume is stochastic. Clients are uniformly distributed between $[0,1]$. A client's location on this line represents its expected data volume. Meanwhile, the actual data volume of a client at d_i is uniformly distributed between $[d_i - m, d_i + m]$. d_i is the expected data volume and m measures the uncertainty of the data volume. However, this uniform distribution applies only to clients with $d_i \geq m$. For clients with $d_i < m$, we do not assume any specific distribution. All we need is their expected data volume, d_i. To make sure the majority of clients have the option to select between different cloud services, we assume $m < \frac{1}{2}$.

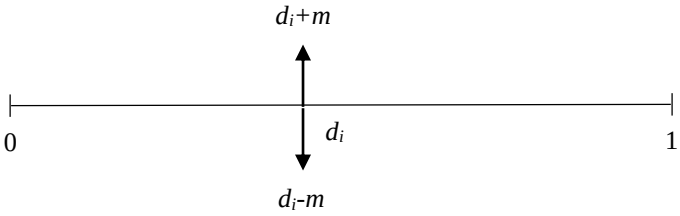

Figure 1. Distribution of Volumes of Clients' Data to Process

When using hybrid cloud services, the clients first deploy the private cloud; they must therefore decide the capacity of private cloud Q_h, incurring development cost $f + cQ_h$, where f is fixed fee and c measures the development cost per capacity. If the actual data exceeds the private cloud capacity, they submit the excess data to the public cloud platform which is offered by Firm 2, paying p_h per unit of data. The client can thereby achieve value v_t per unit data. When using the public cloud, the users just submit all data to the public cloud platform which is offered by Firm 1, paying p_c per unit data. The users can achieve value v_c per unit data. To guarantee the difference between private cloud and public cloud, we assume $v_t > v_c + c$. Otherwise, all clients will only use public cloud services.

Analysis

Monopoly

In this section, we first analyze the monopoly market wherein Firm 1 or Firm 2 are the only cloud provider in the market.

When adopting the hybrid cloud, the client has to deploy the private cloud first. The expected utility of using the hybrid cloud is $Eu_h = v_t \min\{D, Q_h\} + (v_t - p_h)(D - Q_h)^+ - cQ_h - f$. The first two terms represent the expected net utility of the hybrid cloud. It can be divided into two parts: first, when the actual data is below the capacity level, all data processing needs are accommodated by the private cloud, attaining unit value v_t; second, when the actual needs exceed the capacity, the exceeding portion is submitted to the public cloud with the net value $v_t - p_h$. The third term and final term denotes the cost of establishing a private cloud. The client determines an optimal capacity level Q_h by solving the problem $v_t\, prob\{D \le Q_h\} E[D \mid D \le Q_h] + prob\{D > Q_h\}(Q_h v_t + (E[D \mid D > Q_h] - Q_h)(v_t - p_h)) - cQ_h - f$. Solving the problem gives $Q_h^* = d_i + m - \frac{2cm}{p_h}$ and the expected utility $Eu_h = \frac{c^2 m}{p_h} + d_i v_t - cd_i - f - cm$. The marginal client, who gets zero expected utility from using the hybrid cloud, is located at $d^* = \frac{f p_h + cmp_h - c^2 m}{p_h (v_t - c)}$. The expected profit for Firm 2 is :

$$\max_{p_h, f} \pi_2 = f(1 - d^*) + \int_{d^*}^{1} prob\{D > Q_h^*\}(E[D \mid D > Q_h^*] - Q_h^*) p_h dd_i \text{ s.t. } c \le p_h \le v_t \qquad (1)$$

The constraint gives an upper bound and a lower bound to the hybrid price. The upper bound v_t guarantees nonnegative utility of the public cloud component of hybrid cloud services. The lower bound c is the essential condition, below which the clients won't choose to use the hybrid cloud.

When using public cloud, the expected utility for a client located at d_i is $Eu_c = d_i(v_c - p_c)$. The client neither needs to decide the capacity level nor pay an upfront fee.

The expected profit for Firm 1 is :

$$\max_{p_c} \pi_1 = \int_0^1 x p_c dx \text{ , s.t. } p_c \le v_c \qquad (2)$$

The constraint can make sure the clients are willing to deploy the public cloud.

After analyzing the optimal strategies of Firm 1 or Firm 2, we get proposition 1.

Proposition 1: *If the market is monopoly:*

a. If there only exists a cloud computing provider in the market, the price of public cloud is $p_c^* = v_c$ *and Firm 1 get optimal profit* $\pi_1^* = \frac{v_c}{2}$. *The market share is 1.*

b. If there only exists a hybrid cloud provider in the market, the fixed fee of hybrid cloud is $f^* = \frac{c^2 m - (c + 2cm)v_t + v_t^2}{2v_t}$, *the price* $p_h^* = c$ *and Firm 2 can get optimal profit* $\pi_2^* = \frac{(c^2 m - cv_t + v_t^2)^2}{4(v_t - c)v_t^2}$. *The market share is* $\frac{c(2m-1)v_t + v_t^2 - c^2 m}{2v_t(v_t - c)} < 1$.

Proposition 1 shows that if there is only the public cloud provider in the market, all clients will use the public cloud service. As the price is $p_c^* = v_c$, the consumer surplus is almost zero. When there is only

the hybrid cloud provider in the market, only $\frac{c(2m-1)v_t + v_t^2 - c^2 m}{2v_t(v_t - c)}$ clients will use the hybrid cloud. Meanwhile, $p_h^* = c$ indicates that the hybrid cloud provider impels the clients to use the public cloud services in the hybrid cloud as much as possible.

Competition

In this section, we move to the competition between public cloud and private cloud providers. In this scenario, Firm 1 only offers public cloud services, while Firm 2 offers hybrid cloud services. As discussed above, the expected utility of the hybrid cloud for a client located at d_i is $Eu_h = \frac{c^2 m}{p_h} + d_i v_t - c d_i - f - cm$ and the expected utility of public cloud is $Eu_c = d_i(v_c - p_c)$. The marginal client who is indifferent between choosing hybrid cloud or public cloud is located at $d^* = \frac{f p_h + cmp_h - c^2 m}{p_h(v_t - c + p_c - v_c)}$. Firm 1 serves clients located between $[0, d^*]$ and firm 2 serves clients located between $[d^*, 1]$. From the market share, we obtain Proposition 2.

Proposition 2: *When there are both a public cloud provider and a hybrid cloud provider in the market, the clients with less data to process prefer the public cloud services, and the clients with greater data processing needs prefer the hybrid cloud services.*

Proposition 2 is consistent with the findings in some reports[2], which show that the large enterprises and government in China cannot feasibly adopt the public cloud due to concerns about data privacy and security. Alternatively, they are apt to build a private or hybrid cloud independently. Proposition 2 indicates that our model is in line with the industry.

Facing the competitive market, firm 1 maximizes its profit by deciding p_c:

$$\max_{p_c} \pi_1 = \int_0^{d^*} x p_c dx \text{, s.t. } p_c \le v_c \tag{3}$$

The constraint guarantees nonnegative utility of public cloud. Firm 2 maximize its profit by deciding fixed fee f and hybrid price p_h:

$$\max_{p_h, f} \pi_2 = f(1 - d^*) + \int_{d^*}^1 prob\{D > Q_h^*\}(E[D \mid D > Q_h^*] - Q_h^*) p_h dd_i \text{, s.t. } c \le p_h \le v_t \tag{4}$$

Eq. (4) consists of Firm 2's profit from the private cloud and that from the public cloud.

Solving the above maximization problems simultaneously, we obtain Proposition 3.

Proposition 3. *When Firm 1 and Firm 2 compete with each other, the market equilibriums are:*

Case 1($c + 2v_c - v_t > 0$):

Firm 1 sets the public cloud price $p_c^* = v_t - c - v_c$. Firm 2 sets the fixed fee $f^* = \frac{2v_t - 2c - cm - 2v_c}{2}$ and hybrid cloud price $p_h^* = c$. In this equilibrium, Firm 1 can achieve profit $\pi_1^* = \frac{(c(2+m) + 2v_c - 2v_t)^2}{32(v_t - c - v_c)}$ and Firm 2 can get profit $\pi_2^* = \frac{(2v_t - c(2-m) - 2v_c)^2}{8(v_t - c - v_c)}$.

Case 2($c + 2v_c - v_t \le 0$):

[2] http://finance.sina.com.cn/stock/stockzmt/2019-02-20/doc-ihqfskcp6774350.shtml

Firm 1 sets the public cloud price $p_c^* = v_c$. *Firm 2 sets a fixed fee* $f^* = \frac{v_t - c - cm}{2}$ *and the hybrid cloud price* $p_h^* = c$. *In the equilibrium, Firm 1 can get profit* $\pi_1^* = \frac{v_c(v_t - c - cm)^2}{8(v_t - c)^2}$ *and Firm 2 can achieve the profit* $\pi_2^* = \frac{(v_t - c(1-m))^2}{4(v_t - c)}$.

In the competition between public and hybrid cloud providers, the equilibria are divided into two parts in terms of the utility difference between the two options. When there are great differences between the public cloud and the hybrid cloud ($c + 2v_c - v_t \le 0$), the public cloud price will be set to fully appropriate the consumer utility of public cloud clients. Firm 1 thus can charge a monopoly price. Further, the public cloud price increases with the value of the public cloud.

When the difference between the public cloud and the hybrid cloud is low ($c + 2v_c - v_t > 0$), the competition is increased by their similarities. In a market where the public cloud value is high or the hybrid cloud value is low, the hybrid cloud provider has to offer a lower fixed fee to compete with the public cloud provider, who also reduces its public cloud price. While when the gap between the two types of cloud computing is high, the public cloud price increases with the public cloud's value because the market is segmented into two parts by the difference between cloud computing values. In its own market segment, the public cloud provider can charge a higher price due to a higher public cloud value. From the analysis, we obtain Proposition 4.

Proposition 4. *When unit value provided by public cloud service and hybrid cloud service are highly differentiated, there is a segment market where the public cloud provider charges a monopoly price. The public cloud price increases with the public cloud value.*

When they are less differentiated, the market is competitive such that the public cloud provider has to charge a lower price to compete with the hybrid cloud provider. The public cloud price and the fixed fee decrease with the similarity of two cloud values ($v_t - v_c$).

Summarizing Firm 2's strategy in the monopoly market and competitive market gives Proposition 5.

Proposition 5. *Whether or not there is a public cloud competitor, the hybrid cloud provider is willing to charge the lowest fee for its public cloud service.*

Proposition 5 indicates that the hybrid cloud provider prefers to offer its public cloud services at a low price. In this way, the hybrid cloud encourages the clients to use its public cloud services as much as possible. Clients can alleviate their concerns about data uncertainty and the hybrid cloud provider can achieve more profits.

Finally, analyzing the clients' strategies when deploying the hybrid cloud gives proposition 6.

Proposition 6. *When using the hybrid cloud service, the clients deploy the private cloud only to handle certain data processing needs. All uncertain needs are transferred to the public cloud services offered by the hybrid cloud provider.*

The hybrid cloud price decreases to c in equilibrium. In this way, the hybrid cloud clients set the capacity to be $d - m$ and processes data in the public cloud portion as much as possible. All uncertain data are submitted to the public cloud.

Conclusion

In this paper, we presented a game-theoretical model to analyze the competition between a public cloud provider and a hybrid cloud provider, considering the differences in deployment and payment. First, we investigate the client's strategy in selecting the hybrid cloud or public cloud, finding that clients with more data processing needs are more apt to adopt the hybrid cloud. After that, we studied the equilibrium in the competitive market, finding that when there are great differences between the public cloud and the hybrid cloud, there is a segmented market where the public cloud provider charges a

monopoly price. When there are fewer differences, the market is more competitive. By comparing the hybrid cloud provider's strategy in a monopoly market and a competitive market, we found that the hybrid cloud is willing to charge a low price for its public cloud service. Under these circumstances, clients who deploy the hybrid cloud submit all uncertain data to the public cloud. They only process the certain data in their private cloud.

Our paper is not without limitations. First, we assume that the cloud provider can process all clients' needs. In fact, restricted by the actual capacity, providers must sometimes interrupt their service (Huang et al., 2015). This may influence the equilibrium of the competitive market. Second, as the hybrid cloud provider mainly focuses on hybrid cloud solutions, the capacity of the public cloud service offered by the hybrid cloud provider may be lower than the services provided by the public cloud provider. In other words, the cloud computing value may be diverse in the two parts of the hybrid cloud. Thirdly, we assume all clients bear the same development cost in deploying the hybrid cloud. In practice, costs may vary widely among different clients; for instance, an enterprise with an established in-house data center will bear less cost than an enterprise without one. We intend to explore these issues further in future research.

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