Spring 2020

Pricing the Cloud: An Auction Approach

Yang Lu
Old Dominion University, ziiyuu@gmail.com

PRICING THE CLOUD: AN AUCTION APPROACH

by

Yang Lu
B.S. July 2004, JiLin University, P.R.China
MSc December 2005, The University of Manchester, UK

A Dissertation Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Information Technology & Decision Sciences

OLD DOMINION UNIVERSITY
May 2020

Approved by:

Li D. Xu (Chair)

Xianrong Zheng (Member)

Ling Li (Member)

Kayoung Park (Member)

ABSTRACT

PRICING THE CLOUD: AN AUCTION APPROACH
Yang Lu
Old Dominion University, 2020
Chair: Dr. Li D. Xu

Cloud computing has changed the processing and service modes of information communication technology and has affected the transformation, upgrading and innovation of the IT-related industry systems. The rapid development of cloud computing in business practice has spawned a whole new field of interdisciplinary, providing opportunities and challenges for business management research.

One of the critical factors impacting cloud computing is how to price cloud services. An appropriate pricing strategy has important practical means to stakeholders, especially to providers and customers. This study addressed and discussed research findings on cloud computing pricing strategies, such as fixed pricing, bidding pricing, and dynamic pricing. Another key factor for cloud computing is Quality of Service (QoS), such as availability, reliability, latency, security, throughput, capacity, scalability, elasticity, etc. Cloud providers seek to improve QoS to attract more potential customers; while, customers intend to find QoS matching services that do not exceed their budget constraints.

Based on the existing study, a hybrid QoS-based pricing mechanism, which consists of subscription and dynamic auction design, is proposed and illustrated to cloud services. The results indicate that our hybrid pricing mechanism has potential to better allocate available cloud resources, aiming at increasing revenues for providers and reducing expenses for customers in practice.

The proposed hybrid QoS-based pricing mechanism has the following advantages. (1) Solving problems of fixed pricing strategy. The price of a resource cannot be dynamically modified based on resource usage between supply and demand. Cloud providers will suffer potential revenue loss due to more potential customers will be involved and price will be fluctuated. The QoS level and performance of the cloud services obtained is directly related to the expenses a customer needs to pay. If the same amount of cloud services is used, the higher the performance or the higher QoS level of cloud services a customer requires, the higher prices of the related cloud services will be. (2) The QoS-based pricing model can present a clear reserved price to both providers and customers. Differentiated QoS threshold represents different prices to cloud services; the price itself reflects the user's preference for QoS. Overall, the hybrid pricing mechanism can explore both the two pricing strategies' advantages and to provide supplier and customer expected benefits. (3) Attractive to customers. Based on budget constraints, customers could customize cloud services as they expect. Customers have good opportunity to price/bid the expected cloud services.

As a research on cloud computing, this study is one of leading papers that focus on estimating values of various types of cloud services by mathematical auction design and operational allocation. Some study explores the ideas about fixed pricing strategies, such as pay-per-use, subscription, tiered pricing, and free-of-charge; some study pays more attention on different dynamic pricing mechanisms, such as financial mathematical models and auction designs. This thesis is the first writing talking about a hybrid pricing design that is consists of subscription and dynamic auction design for both existing and newcomers of companies to develop cloud computing in the markets. More important, a QoS-based reference price is proposed for both provider and customer, ideally, most of popular QoS indicators are embedded in the reserved pricing model.

This study is a very good attempt to explore cloud pricing strategy. Most of the studies discuss various cloud pricing strategies from technological or mathematical perspective, but the pricing mechanisms are difficult to implement in practice because they ignore marketing conditions, such as supply and demand, and difficulties of companies, such as usage preference or budget constraint. In this thesis, a real marketing environment is constructed, both existing companies and newcomers would obtain some insights and benefits if they have chance to put the hybrid pricing mechanisms into practice. Firstly, companies can judge the development status of its cloud computing, such as the initiating, developing, and maturing stages. Secondly, providers can improve the comprehensive quality of cloud resources based on different QoS expectations from end-users, such as scalability, elasticity, availability, latency, reliability, security, throughput, capacity, etc. Thirdly, both providers and customers can obtain an accurate estimated reference price. The hybrid QoS-based pricing mechanism has potential to guide providers and customers in the cloud industry.

This thesis is dedicated to the proposition
that the harder you work, the luckier you get, the happier you deserved.

ACKNOWLEDGMENTS

My time as a PhD student at Old Dominion University has been supported by many kinds of people. This page attempts to recognize those who have been most helpful along the way.

First of all, I am deeply indebted to my supervisor, Dr. Li D. Xu. His advice, support and kind encouragement on both professional and private issues have effectively guided me through this winding way. Furthermore, he always led my papers to clear, smart and persuade ones. Without his great support, this thesis would not have been possible.

I am also very grateful to my advisor, Dr. Xianrong, Zheng. His professional expertise and unique thinking into both computer science and information technology stimulated me to brainstorm and systematically design the appropriate mechanisms.

At the same time, I am also indebted to my department chair and advisor, Dr. Ling Li. Her experience, technique and insight into information systems and decision sciences have immensely supported me in designing the mechanism and developing the contexts.

Thanks to my committee member and advisor, Dr. Kayoung Park. She provided me with very valuable mathematical and validating mechanisms. I couldn't make this great progress without her valuable suggestions and great support.

Thanks to my director Dr. Mitsue Shiokawa. During the first-three-year of my PhD study, recommended by Dr. Xu and Dr. Li, she hired me as a part-time data analyst for ODU Online to financially support me and my family.

My PhD study is different from most PhD cases. My PhD study consists of two components, a three-year full-time study and a two-year full-time university lecturer. After three-years full-time studies, under the guidance and support of Dr. Xu and Dr. Li, I got a great chance to become a full-time lecturer at College of Charleston. I was a Visiting Assistant Professor in the Department of Supply Chain and Information Management. I have been working there for two years since August 2018. After two-years discipline, I am capable of teaching courses related to Business Analytics and Decision Sciences. Such as Management Information Systems, Data Visualization, Operational Management, etc. Thanks to the Department Chair Dr. Giaconda Quesada, Professor Marvin Gonzalez, and the Secretary Mrs. Sabrina Holloway! Without their strong support and training, I cannot be transitioning from a PhD candidate to an academic professor.

Thanks to my PhD administrator, Mrs. Katrina J. Davenport. Every time that I had any concerns about study and graduating, she always could find an appropriate approach along with useful information to help me out.

Special thanks to my family, my father and mother, my wife, and my three little boys. Without their consideration and effort, I cannot smoothly finish my PhD degree.

In addition, I have benefited from time spent with friends at ODU. Interdisciplinary discussions with these friends have opened my eyes greatly than expected before.

Each devoted significant time and effort to my thesis, and their suggestions and comments led to substantial improvement in the final product.

NOMENCLATURE

A	Availability
A_x	The function of availability and cloud resource
Ask_j^t	The asking price from provider j
$AskREV_j$	The reserved price of provider j
B_i	Customer i's bidding price
B_j	Provider j's bidding price
Bid_i^t	The bidding price from customer i
$BidREV_i$	The reserved price of customer i
C	The cost of cloud resource
d^{b^*}	The bid density of customer i^*
d	The number of luxury or of high-demand customers
E	Elasticity
E_x	The function of elasticity and cloud resource
F(X)	The function of reserved price
g	The number of poor or of low-demand customers
G	The set of all the possible strategy of a game
i	Customer i
i^-	The losing bidders
j	Provider j
$Load_j^t$	The workload of provider j
M	There exist m sellers, M = $\{m_j$, j = 1, 2, …, m$\}$

N	There exist n customers, N = {n_i, j = 1, 2, …, n}
O_i^t	The other factor impacting the order and price of customer i
P	The marketing price
P_0	The fixed price
P_E	The equilibrium price
P_i^W	A winning customer i's payment
P_R	The reserved price
P_T	The trading price
$P_{(D+)}$	The Price when demand is high
$P_{(D-)}$	The Price when demand is low
Q	The requests from all customers
Q_i	The service request from customer i
Q_i^t	The quantity for certain cloud service that customer wins and uses
R	Reliability
R_x	The function of reliability and cloud resource
$ResMax_j$	The maximum of resources that provider j can provide
$Respond_i^t$	The respond time of Q_i
$ResUsed_j^t$	The total number of other accepted resource requests between time t and the deadline
S	Security
s_i	The game strategy of a certain unit
S_i	The set of game strategies for a certain activity
S_x	The function of security and cloud resource
t_0	The initiating point
t_1	The time when the marketing price equals cost

t_2	The time when the marketing price equals the fixed price
t_3	The time when the marketing price equals the equilibrium price
T_i^t	The length of time the winning customer i will use the service
V	The true value of cloud resource
V_i	The true expected value from customer i
V_j	The true expected value from provider j
X	The QoS metrics
X_i^{D+}	Customer Consumption level when demand is high
X_i^{D-}	Customer Consumption level when demand is low
X_i^t	All levels of cloud resources from a customer *i*
X_j^t	All levels of cloud resources from a provider *j*
$X_{(i,D+)}^{MAX}$	Customer Maximal Consumption level when demand is high
$X_{(i,D-)}^{MAX}$	Customer Maximal Consumption level when demand is low
U	Utility
α	The degree of impact of the workload on the asking price
β	The degree of impact of the workload on the bidding price

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

This chapter is dedicated to describing the overall idea of the study.

1.1 Cloud Computing and Information Systems

Since its inception, cloud computing has been emphasizing its business model in the real world. The success of the business of cloud computing is largely achieved by developing a reasonable and advanced pricing mechanism [1-5]. It is critical to develop a pricing strategy for cloud service that helps providers grasp competitive advantage and obtain more revenues. At the same time, the fundamental changes in the way of work and business are brought by cloud computing, leading to the separation of customer and computing resources [6-11]. When customers need computing resources, they only need to pay a fee to cloud providers. Hence, a viable pricing strategy is needed to fulfill the requirements of customers [12-18].

Cloud computing not only has a huge impact on the application of information storage, interaction and computing technologies, but also promotes a new round of business innovation and revolution [19-23]. From the end of 2006, IT giants Google and Amazon started promoting cloud computing industry. Subsequently, companies such as IBM, Microsoft, AT & T and SalesForce followed and launched their own cloud services [24-26]. Cloud computing is an Internet-based and infrastructure-shared IT service model. By virtualizing and dynamically configuring computing resources, platform, software, hardware, and data-related services can be provided. Customers do not need to purchase equipment in advance or care about specific computing processes or maintenances. They only need to submit a request to get the service and then pay based on the usage [27, 33].

Cloud computing, as an emerging and popular terminology in the ICT industry, is potential to revolutionize the way that companies process business intelligence. Customers do not need to purchase equipment in advance or care about specific computing processes or maintenances [34, 35]. They only need to submit a request to get the service and then pay based on the usage. It is of great practical significance to develop a pricing strategy for cloud service that helps providers grasp competitive advantage and obtain more revenues. It has become the development of the national core strategy of the next generation of information technology [36-39]. Currently, leading IT companies are gearing up to make business in cloud services: Amazon.com, Google, Microsoft, and IBM. These companies develop cloud computing focusing on different cloud services that consisting of the power of cloud computing and the Internet [40-43].

With the continuous developing accomplishment of cloud computing and the increasing requirement of cloud services, the cloud computing service market has entered a period of rapid growth. Faced with the competition among the cloud industry, cloud pricing will be transformed from the unilateral (fixed) pricing strategies focusing on provider's revenue to the bilateral (dynamic optimal auction) pricing strategies that benefit to both provider and customer, which will be more suitable for the development of cloud computing [44, 45]. Meanwhile, companies will seek potential approaches to accompany with cloud computing for normal operation activities and information system-related transition; individuals will use more cloud-based services and resources through the Internet or other possible network systems [46, 47].

1.2 Purpose and Contribution

I address the issue of designing a novel hybrid QoS-based auction design, through which cloud services are distributed between providers and customers, along with different pricing strategies, i.e., subscription and double auction procedure. The goals are to (1) propose QoS-embedded metrics to price and match cloud services between different provider' services and customers' expectations, (2) construct a combination of fixed pricing and bidding pricing strategies to provision available services between multiple providers and customers, and (3) flexibly and dynamically set up a hybrid QoS-based pricing strategy to optimize provider revenues.

This study potentially plays important roles in academia and practice. This is the first paper combine QoS metrics (technological perspective of cloud computing) and dynamic pricing mechanisms (subscription and auction design) together. It is potential to offer certain insights and guidance for researchers who are interested in cloud pricing. Variety of auction can be designed and explored, especially double and combinatorial auction designs. QoS metrics are good variables to estimate values of cloud computing, and cloud computing includes other technological factors impacting the overall performance and price. A hybrid QoS-based pricing mechanism is built to effectively distribute available cloud resources based on marketing conditions, such as when supply > demand, pricing strategy is different based on marketing price. The pricing strategy adopted with should benefit to providers or customers, aiming at achieving better outcomes. The model presents an appropriate reserved price of cloud resources, which will be as reference to both providers and customers. Throughout the complete pricing process, a provider could easily locate its own pricing strategies and the status of its cloud computing development; a customer could easily seek available cloud services based on its own QoS expectations and budget constraints.

1.3 Method and Procedure

Based on pricing theory in marketing (supply and demand) and game theory in economics, I construct three cloud development stages that represent different relations between supply and demand. Such as the initiating stage, the developing stage, and the maturing stage. For each stage, I propose an appropriate pricing strategy. For instance, in the initiating stage, subscription (fixed pricing strategy) is proposed, which is better than a pay-per-use pricing strategy; for both the developing and maturing stages, dynamic auction design is adopted with, which can help providers attract more potential customers and obtain more revenues and assist customers figure out cloud prices and save expenses. According to mathematical proof, the proposed hybrid pricing mechanism has certain advantages and can fulfill different expectations for customers and providers. The details are illustrated in Chapter 3, 4 and 5.

1.3.1 Marketing conditions.

The initiating stage is between $t_0 \sim t_1$. And the marketing price (P) is lower than the cost of cloud resource (C). In the market, there are only a few customers with plenty of cloud resources from multiple providers. This stage is not a good time for companies to gain revenues, but to attract potential customers. Also, it is not necessary to change the price instantly. A better pricing strategy for company to adopt with is to offer customers discount or promotional price. An example is Amazon AWS who offers customers free-of-charge for certain cloud services for one year.

The developing stage is between $t_1 \sim t_2$. And the marketing price (P) is lower than the fixed price of cloud resource (P_0) but higher than the cost of cloud resource (C). In the market, the quantity of customers will be increasing, due to the cloud marketing is growing. This stage is the first time for companies to gain revenues. But, if a company adopts with the fixed pricing strategy, it may encounter potential revenue loss that expressed in Figure 3-1. Hence, it is better for a company to seek to change the price instantly. A better pricing strategy for company to adopt with is to offer customers dynamic price. The price will be modified based on marketing fluctuation between supply and demand. Although for a certain customer's resources, a provider offers a lower price, a lower price based on supply and demand will attract more customers to purchase cloud resources, leading to the economies of scale. Companies will obtain more revenues overall eventually. An example is Amazon AWS who offers customers Spot Instance for certain cloud services.

The maturing stage is between $t_2 \sim t_3$. And the marketing price (P) is lower than the equilibrium price of cloud resource (P_E) but higher than the fixed price of cloud resource (P_0). In the market, the quantity of customers will be increasing, due to the cloud marketing is growing. This stage is the second time for companies to gain revenues. But, if a company adopts with the fixed pricing strategy, it may encounter potential revenue loss that expressed in Figure 3-1. Hence, it is better for a company to seek to change the price instantly. A better pricing strategy for company to adopt with is to offer customers dynamic price. The price will be modified based on marketing fluctuation between supply and demand. An example is Amazon AWS who offers customers Spot Instance for certain cloud services.

1.3.2 The Function of QoS-based reserved price.

The QoS metrics (X) is consisting of availability ($A_{(x)}$), reliability (R_x), elasticity (E_x), etc. The bidding price is based on the reserved price (P_R) that is applicable to both seller and buyer. *x* refers to all possible features that influence the performance of QoS in cloud computing, such as CPU power, speed, storage, location, etc.

The QoS metrics (X):

X

A (Availability), A_x

E (Elasticity), E_x

R (Reliability), R_x

S (Security), S_x

…

The function that expresses the reserved price is:

$$P_R = F(X) = F(A_x, E_x, R_x, S_x, \dots)$$

1.3.3 The Hybrid pricing mechanisms

The hybrid QoS-based piecing mechanism consists of subscription and dynamic auction design for different marketing conditions between supply and demand. For instance, in the initiating stage, a subscription pricing strategy will be used, aiming at attracting potential customers and expanding marketing share; in the developing and maturing stages, a dynamic double auction pricing strategy will be employed to benefit to both providers and customers. Specifically, when the cost of cloud resource is higher than the marketing price in cloud market (the initiating stage), a fixed subscription price strategy will be adopted; when the marketing price is higher than the cost of cloud resource but lower than the fixed price of cloud resource (the developing stage), a dynamic auction design will be implemented; when the marketing price is higher than the fixed price of cloud resource but lower than the equilibrium price of cloud resource (when supply equals to demand, the maturing stage), a dynamic auction design will be implemented. The following table (Table 1-1) depicts the details.

TABLE 1-1

Pricing Strategies of Three Development Stages

Developing Stage	Pricing Strategy
Initiating	Subscription (Fixed Pricing Strategy)
Developing	Dynamic Auction Design (Dynamic Pricing Strategy)
Maturing	Dynamic Auction Design (Dynamic Pricing Strategy)

1.4 Outline of The Thesis

The construct of this research is outlined below. Chapter 1 is the introduction. A brief explanation of cloud computing and information systems is addressed, as well as the purpose and contribution of the thesis. Moreover, methods used in the thesis and detailed procedures are introduced and explained. Chapter 2 provides a common understanding of cloud computing and game theory (auction design), discusses various cloud computing pricing strategies, and points out the unresolved issues related to the extant pricing mechanisms, specifically Quality of Service (QoS), such as availability, reliability, latency, security, throughput, capacity, scalability, elasticity, etc. Chapter 3 introduces three developing stages (the initiating stage, the developing stage, and the maturing stage) in details, illustrates QoS indicators that impact cloud evaluations, and proposes the QoS-based reserved model to cloud resources. Chapter 4 illustrate the proposed hybrid QoS-based pricing strategies, such as subscription and dynamic auction design, the bidding procedure is depicted as well. The comprehensive detailed models and mathematical explanations are included in this chapter. Chapter 5 points out several limitations and potentials for future direction. For instance, the issues of current cloud pricing mechanisms, the marketing condition of supply and demand, the decentralized cloud trading platform, and the impact of QoS-based pricing strategy on customer purchasing behavior as an empirical study. Chapter 6 concludes the study and present some insights of cloud pricing and developing in future.

CHAPTER 2

BACKGROUND OF THE STUDY

This chapter is dedicated to discussing the background of the study.

2.1 Introduction to Cloud

2.1.1 The Concept of Cloud Computing and The Basic Elements

"Cloud computing: A model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five core technical characteristics, three service models, and four deployment models"[1] [48-50].

Cloud computing is not a new type of computing technology, also a new type of network application programming. The core concept of cloud computing is Internet-centric, providing fast and secure cloud computing services and data storage on websites so that everyone can use the Internet. Huge computing resources and data centers can be used by anyone. After the Internet and computers, cloud computing is an innovation in the information age. The following depict (Fig. 2-1) is a comprehensive view of cloud computing.

[1] This is one of the popular definitions from NIST (National Institute of Standards and Technology).

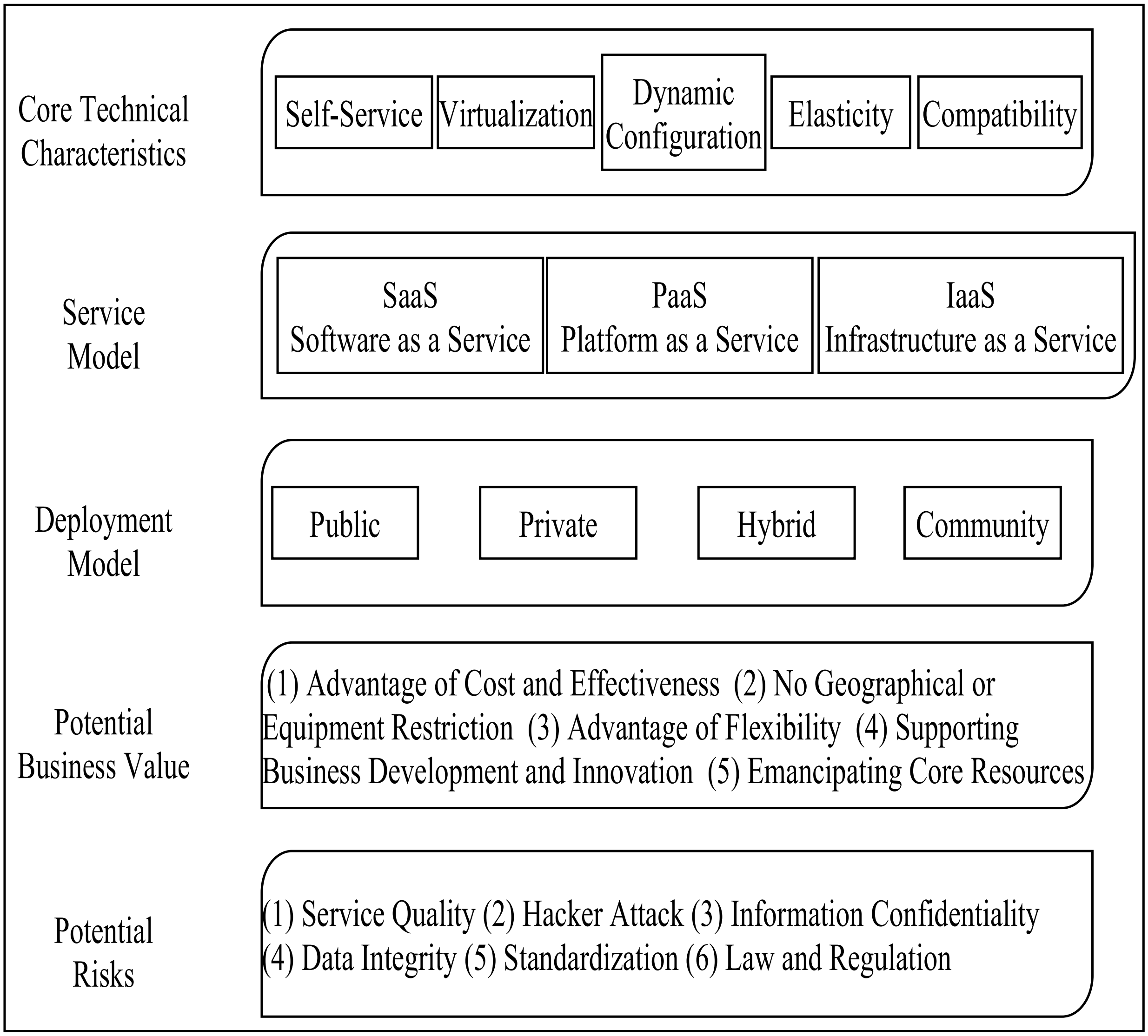

Fig. 2-1. A Comprehensive View of Cloud Computing

2.1.2 The Features of Cloud Computing

In short, the core technical characteristics of cloud computing are mainly reflected in the following five aspects [51-55]: (1) On-demand Self-service. If users need cloud services, they can run on the cloud platform themselves without having to communicate with the cloud provider every time. (2) Virtualization. Cloud computing storage and computing resources have been virtualized to users and cannot be accessed directly. As we all know, the physical platform and environment in which applications are deployed have no spatial connection. It is a virtual platform that can complete data backup, migration and expansion of corresponding terminal operations. (3) Dynamic configuration. Cloud computing can dynamically assign computing tasks to different resources in the cloud, and can also provide resources to different customers simultaneously. Cloud computing achieves the purpose of dynamically configuring the level of virtualization and expanding applications.; (4) Resource elasticity. Cloud computing can flexibly allocate and release resources to meet the different needs of different users for computing resources. (5) Technical compatibility. Users can enjoy cloud computing services through any form of network access device [3]. It can be seen that the compatibility of cloud computing is very strong. Not only is it compatible with low-profile machines and hardware products from different manufacturers, but it can also perform higher-performance calculations on peripherals.

2.1.3 The Three Service Models of Cloud Computing

Generally, cloud computing includes three major categories: infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). Among the three service models, SaaS is the most popular service that most companies are conducting and provisioning in practice. A detailed description is in the following figure (Fig. 2-2). NIST clearly defined all the three service models. This study also adopts the same thinking to analyze some possible pricing mechanisms for cloud services. The extant study always clarifies which service model (s) the study targeted at, but this study won't really distinguish the three service models. Similarity and difference among these three service models are not the focus in this thesis. Hence, the proposed hybrid QoS-based dynamic pricing mechanisms are applicable to all the three service models, although in practice for a certain service model, the mechanism might need some adjustment.

IaaS	Amazon AWS, Google App Engine, Google Compute Engine, IBM Cloud, Microsoft Azure, Cisco Metapod, DigitalOcean, Linode
PaaS	Amazon AWS Elastic Beanstalk, Google App Engine, Microsoft Azure, Salesforce Heroku, Engine Yard, OpenShift, Apache Stratos
SaaS	Amazon AWS, Google App Engine, Google Compute Engine, BigCommerce, Salesforce, Dropbox, MailChimp, ZenDesk, DocuSign, Slack, Hubspot, …

Fig. 2-2. Service Models and Providers

IaaS (Infrastructure as a Service) provides customers with the computing resources, including servers, networks, storage, and data centers. “The capability provided to the consumer is to use the provider’s applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g., web-based email), or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user specific application configuration settings”[2] [48], [56, 57].

PaaS (Platform as a Service) provides consumers with a cloud-based environment to develop applications. Customers do not need to buy and manage the underlying cloud

---

[2] NIST definition.

infrastructure. Such as hardware, software, and operating systems. "The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment[3]" [48], [58, 59].

SaaS (Software as a Service) provides customers with cloud-based applications, which customers can access through the Internet. "The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications; and possibly limited control of select networking components (e.g., host firewalls)[4]" [48], [60-62].

Currently, many companies are pursuing cloud computing on IaaS, PaaS, and SaaS, especially SaaS is the most popular resources. The following table (Table 2-1) lists major companies and services. In the real business world, as a cloud-related company or provider, it is better to implement all possible services not focusing on only one specific service models, e.g., SaaS. More and more companies try to collaborate resources or partner with other companies to develop more service models to attract more customers and gain more revenues as possible [62-64]. Some other type of cloud service is defined, such as Databased as a Service, Analytics as a Service, Blockchain as a Service, etc. This thesis still follows the same definitions from NIST that depicts the three major service models as the majority; other newly developed service model

---

[3] NIST definition.
[4] NIST definition.

also accompanies with the same features of the three major service models. Even to most of the existing companies, they have some limitations to develop service models other than the three major models, e.g., limited investment and resources, the marketing focus and sales strategies, technological preference and information advantages [65-67].

TABLE 2-1

Resources of Service Models

Service Model	Products	Customer Activity
IaaS (Infrastructure as a Service)	Amazon: AWS EC2 (Elastic Compute Cloud), AWS S3 (Simple Storage Services), AWS Glacier;	Processing IT-related infrastructure operations
PaaS (Platform as a Service)	Amazon AWS Lamda, Heroku Platform, IBM Cloud Kubernetes, Salesforce Lightning Platform, Wordday Cloud Platform	Developing and deploying resources in a cloud platform
SaaS (Software as a Service)	Google Apps, DropBox, HubSpot, Zoom Conference Meeting,	Adopting with cloud services for business operations

2.1.4 The Four Deployment Models of Cloud Computing

There are four deployment models (Table 2-3) for cloud computing, which basically include all cloud services and platforms [68-71]. The four models are: (1) Public cloud. Public cloud refers to cloud services provided to all individuals and businesses. Users can share infrastructure, development platforms and application terminals; (2) Private cloud. Private cloud is a cloud service for a specific business or organization provided by the enterprise itself or a third-party vendor; (3) Community Cloud. A group cloud is a cloud service for a specific group. Related groups often have the same needs, tasks, or interests, and related services can be provided by companies in the group or a combination of multiple companies. It can be provided by third parties; (4) Hybrid cloud. Hybrid cloud refers to a cloud service model that integrates the above two or three models. This usually happens when a single service model cannot meet user needs [72-74].

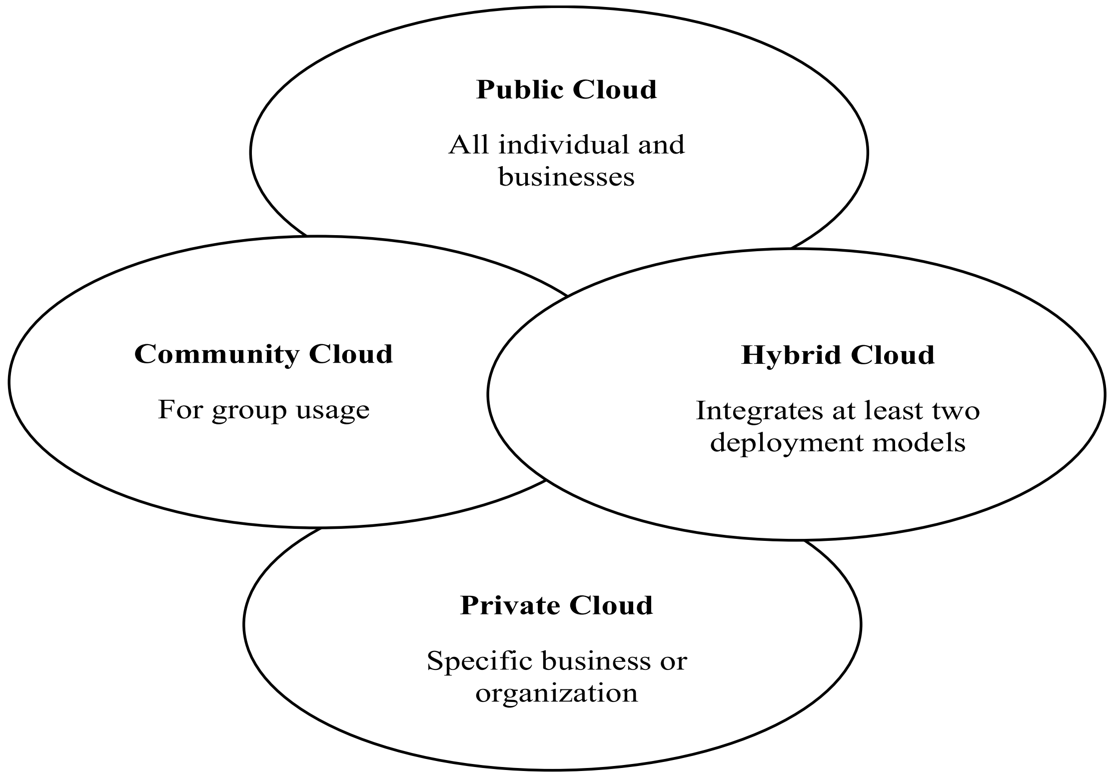

Fig. 2-3. Deployment Models of Cloud Computing

2.1.5 The Potential Business Values of Cloud Computing

The potential business values of cloud computing are summarized from the following five aspects:

(1) Advantages of cost and effectiveness. The dynamic configuration and resource elasticity of cloud computing has the advantages of economies of scale, thereby decreasing the expenses and increasing the effectiveness of use for users [75-77].

(2) No geographical or equipment restrictions. The virtualization and technology compatibility features of cloud computing can ensure that users can access cloud resources in different situations and locations; in addition, work data will not be lost even if a computer or mobile phone is lost [78-80].

(3) Advantage of flexibility. Cloud computing's self-service and resource resilience can bring application flexibility to individual and business users. Cloud computing's low asset specificity and low conversion costs also enable users to learn, master, and use the latest technologies and business management processes on cloud platforms [81-84].

(4) Supporting business development and innovation. With the support of virtualization and self-service, cloud computing can continuously provide enterprises with various services. Therefore, when business needs change quantitatively or qualitatively, companies can use cloud computing to quickly expand their business while maintaining the standardization and quality stability of the products or services. In addition, the various service functions of cloud computing can lay the technical foundation and provide an experimental environment for enterprises to conduct business and service innovation. Businesses can continue to experiment and learn to maintain strong innovation momentum and capabilities [85-88].

(5) Emancipating the core resources of the enterprise. Because cloud computing can easily meet the basic IT needs of business users, companies using cloud computing can invest more human, material and financial resources to develop core and value-added businesses [89-94].

2.1.6 The Risks of Cloud Computing

(1) Service quality issues. Because cloud resources are automatically implemented, users cannot control the quality of service of cloud computing. It is difficult to take interventions even if they encounter quality of service issues [95-97].

(2) Hacker attack. Hacking refers to the use of some illegal means to enter the cloud computing security system, causing some damage to the cloud computing security network.

After the invasion, the operation is unexpected, and the losses caused are also a lot. The damage caused is unpredictable [98-100].

(3) Information confidentiality. Information confidentiality is the main problem of cloud computing technology and the main problem of current cloud computing technology. For example, some businesses share user resources. The particularity of the network environment allows people to freely browse related salary resources. Information resource leakage is inevitable. If the technology is not confidential enough, it may seriously affect the owner of the information resource [101-103].

(4) Data integrity. When using cloud computing technology, data may not be stored in the same location, rather than in a single system, which affects the integrity of data resources and makes it difficult to operate effectively. Another situation is that the service provider cannot correctly and effectively manage the user's data information, which will affect the integrity of the data storage, and the application of the information is difficult to play [104, 105].

(5) Standardization issues. Failure to standardize data and processes across different cloud computing providers may lead to issues, such as compatibility, technology application flexibility, and strategic planning [106-108].

(6) Incomplete laws and regulations. Incomplete laws and regulations related to cloud computing technology are also a major problem. It is necessary to improve its relevant laws and regulations. At present, laws and regulations are not complete, and the role of cloud computing technology is still limited. From the current application of cloud computing technology in computer networks, it lacks perfect security standards, lacks perfect service level agreement management standards, and has no clear legal responsibility for security issues. In addition, the lack of a complete cloud computing security management loss computer system and liability

assessment mechanism, and the lack of legal norms also restrict the development of various activities, and the cloud computing security of computer networks is difficult to guarantee [109-111].

2.2 Game Theory and Auction Design

2.2.1 Concept of Game Theory

Game theory refers to a mathematical model abstracted from the political, economic and military activities of human society. In this kind of activity, there are participating units or people, called participants or people in the game [112-114]. Participants reflect their participation in this activity by choosing certain actions. Participants' activities involve certain interests of themselves and other participants. This interest is not only related to their own behavior, but also to the behavior of other participants. Game theory mainly studies the rational behavior of participants in such activities, and studies the final result of the game under the premise that all participants adopt rational behavior [115-117].

Game theory is a discipline specializing in the study of conflicts and cooperation among rational individuals. Game theory was founded in 1944 by J. von Neumann and O. Morgenstern. The famous book "Game Theory and Economic Behavior" was published in 1944. But its rapid development was in the 1950s. After John Forbes Nash Jr. published two basic non-cooperative game theory papers[5]. Cooperative game theory and non-cooperative game theory are two components of game theory, but in recent years, game theory has not only developed rapidly, but also has been more and more widely used in economics and other fields [118-120].

---

[5] Nash, John (1950) "Equilibrium points in n-person games" Proceedings of the National Academy of Sciences 36(1):48-49, and Nash, John (1951) "Non-Cooperative Games" The Annals of Mathematics 54(2):286-295.

2.2.2 Elements of Game Theory

In game theory, strategic game models usually consist of three elements [112-117].

(1) Participant Set: To construct a game theory model, you need to know who participate in this activity. Participants do not necessarily refer only to individuals, but also refer to person, also include government, enterprise, region, country, etc. The set of all participants becomes the set of participants, denoted as $N = \{1, 2, 3, \dots, i, \dots, n\}$. $i \in N$ is participants.

(2) Strategy: In a game model, s_i denotes the participant i's strategy, such as S_i, $i \in N$.

Every participant needs to choose a strategy, constructing a strategy vector s = $(s_1, s_2, \dots, s_i, \dots, s_n)$ as a strategic set, $s_i \in S_i$.

$$\prod_{i=1}^{n} S_i = \{\mathrm{s} \ = \ (s_1, s_2, \dots, s_i, \dots, s_n) \,|\, s_i \in S_i\}$$

(3) Payoff Model: It is defined as on the strategy combination set S_i, which takes a value in the real space R and is expressed as $u_i(s)$. It is used to describe certain gains or losses suffered by participant i under the strategy combination $s_i \in S_i$. The utility function $u_i(s)$ in game theory is controlled not only by participant i, but also by i's opponent. In other words, the interests of the participants are mutually restrictive.

The strategy game model can be expressed as：

$$G = \langle N, S_{1,} S_2, \dots, S_i, \dots, S_n, \rangle$$

2.2.3 Classification of Game Theory

Game theory are classified as cooperative and non-cooperative models (whether or not cooperation is strongly restricted) according to the behavior of cooperative participants. Starting with participants choosing actions simultaneously or at different times, non-cooperative games are categorized into static and dynamic models. According to the participants' understanding information of the game itself, non-cooperative games are classified into models with complete information and incomplete information. Hence, non-cooperative model consists of four basic types: static model with complete information, dynamic model with complete information, static model with incomplete information, and dynamic model with incomplete information[113-115], [117,118].

2.2.4 Nash Equilibrium

In the game model, how each participant chooses strategies rationally, and on the premise that each participant is rational, the outcome of the game are the two focuses of debate. In game theory, it is assumed that each participant is rational, they can correctly predict the opponent's behavior, and under this premise, their own reward will be maximized. Under the assumption of participants rational behavior, the participants' reasonable strategy portfolio can be described by the following Nash equilibrium [121, 122].

Definition 1. $G = <N, S_{1,}S_2, \dots, S_i, \dots, S_n, >$is a generalized game model, strategic portfolio $s^* = (s_i^*, s_{-i}^*)$, $s_i^* \in S_i$ is a Nash Equilibrium. If $\forall\ i \in N$, and $s_{-i} = s_{-i}^*$, the participant i's optimal strategy is:

$$u_i(s_i^*, s_{-i}^*) = \max_{s_i \in S_i} u_i(s_i^*, s_{-i}^*)$$

Game theory believes that rational participants should choose strategies in Nash equilibrium s_i^*. If the participant *i* can expect that the opponent will not choose s_{-i}^*, he or she will choose s_i^*, then the opponent's reward may decline. If he or she does not choose s_i^*, the opponent chooses s_i^*, which may reduce your payment. Therefore, each participant *i* does not deviate from the enthusiasm of Nash equilibrium strategy s_i^* [123-125].

2.2.5 Cases of Nash Equilibrium

Case I. The Prisoner's Dilemma.

The police suspected that persons A and B had committed the crime of partnership, but there was no conclusive evidence. Thus, the court relied mainly on the confession of the offender in the judgment. The specific possibilities are as follows:

(1) If neither of them admits the crime they committed, they can only be sentenced to one year in prison for the misdemeanor found.

(2) If one of them pleads guilty, they will be acquitted for their good guilty attitude. Another person was sentenced to eight years in prison for fighting crime.

(3) If both plead guilty, they will each be sentenced to 5 years in prison.

The table (Table 2-2) below shows the payoffs.

TABLE 2-2

Prisoner's Dilemma

Prisoner A or B	Confess	Defense
Confess	5, 5	0, 8
Defense	8, 0	1,1

From a mathematical point of view, the theory is reasonable, that is, the choice is confession. However, this is obviously inappropriate in the sociological field of multidimensional information collaboration. In ancient China, bribery between officials was called "wrong rules" rather than trying to find them. This is because the deterrent effect of social systems on people's behavior forces people's decision-making to change. For example, from a psychological perspective, the cost of choosing a confession will be greater. One side pleaded defense, the other side pleaded defense. Then, the subsequent acts of revenge, and therefore the "betrayal" role that is not easy to become an insider will fail him.

The increase in proportion between 8 and 10 years will be diluted, human dignity will cause revenge and slightly undermine the "rules." In order to deal with things that are closer to the facts, we must have as much relevant information as possible and reasonably weight the analysis. The dynamics of human motion is very complex, so the plight of prisoners can only be used as a reference for simplified models and specific decisions.

According to strategic portfolio $s = (s_{1,}s_2)$, $s_i \in S_i$, $i = 1, 2$. The two persons have the identical strategic portfolios, $S_1 = S_2 = \{Confess, Defense\}$. The payoffs of the two prisoners are:

$$u_i(s_{1,}s_2) = \begin{cases} -5 & s_1 = s_2 = Confess \\ 0 & s_1 = Confess, s_2 = Defense \\ -8 & s_1 = Defense, s_2 = Confess \\ -1 & s_1 = s_2 = Defense \end{cases}$$

$$u_i(s_{1,}s_2) = \begin{cases} -5 & s_1 = s_2 = Confess \\ 0 & s_1 = Defense, s_2 = Confess \\ -8 & s_1 = Confess, s_2 = Defense \\ -1 & s_1 = s_2 = Defense \end{cases}$$

Case II. The Beauty’s Coin

A beauty comes to chat with a gentleman and asks to play games with him. The beauty advice: "Let's show the coin's two sides, positive or negative. If we are all positive, I give you 3 dollars, if we are all negative, I give you 1 dollar, and you give me 2 dollars. The gentleman will participate in the game anyway. The potential results are indicated in the following table (Table 2-3).

TABLE 2-3

A Beauty's Choice

Gentleman or The Beauty	Front	Back
Front	3, -3	-2, 2
Back	-2, 2	1, -1

Suppose the probability of front side is x and the probability of back side is $(1-x)$. In order to maximize the gentleman's income, when the beauty's coin is front or back, the income should be equal, otherwise the beauty can change the probability of the front and back sides at any time and reduce the total income.

It is the same as the maximum return when the beauty moves on. Solve the problem, which means that there are 3 front sides every 8 times, and 5 back sides are our best strategy. Substitute $x = 3/8$ into the income expression $3 * x + (-2) * (1-x)$ to get each expected income. The calculation result is -1/8 dollar.

Similarly, we assume that the beauty has a front probability of (y), a back probability of ($1-y$).

Whenever the expected outcome of the beauty is $2 (1-y) -3y = 1/8$ dollar, the solution y is also equal to 3/8. This tells us that with the best strategy adopted by both parties, an average of 1/8 won can be paid for each beauty's winning. In fact, if the beauty adopts the decision of (3/8, 5/8), no matter which plan the gentleman will use, this situation cannot be changed. If both parties are both front sides of the coin, the expected return is (3 + 3 + 3-2-2-2-2-2) / 8 = -1 / 8 dollar.

If both are back sides, the expected return is (-2-2-2 +1 +1 +1 +1 +1 +1 +1) / 8 = -1 / 8 dollar. And any strategy is nothing more than a linear combination of the above two strategies, so it can still be expected to be -1/8 dollar. However, when the gentleman also uses the best strategy, he can at least guarantee the least loss. Otherwise, he will be targeted by the strategy adopted by the beauty, and he will lose more. This game model doesn't seem very useful, but in fact, it may involve one of the most important models in financial market pricing: the pricing weighted model.

Generally speaking, the foundation of game theory is to explore the competitive phenomenon in the form of a game, and to employ mathematical and logical approaches to analyze the rules of activities. Because there are game participants, there must be a game ruler. A deep understanding of the nature of competitive behavior will help us analyze and grasp the relationship between things in competition, and make it easier for us to formulate and adjust rules, so that the rules can ultimately operate according to our intended goals [124-126].

2.2.5 Different types of auction processes

If a product or service does not have a reference to estimate its true value, an auction design is a suitable way to track prices and distribution. Because of uncertainty, we do not have a standardized mechanism for adoption; indeed, an auction design can take advantage of any uncertainty to overcome obstacles. Game-based auctions can estimate resources to a certain degree, relying mainly on participants' bids rather than on the fluctuations of supply and demand [115-118], [124, 125]. The below picture addresses various auction designs (Fig. 2-4).

Number of Goods			
	ONE	**1:N or M:1** **Single-Sided Auction** English/Dutch Auction Sealed-Bid Auction Reverse Auction	**M:N** **Double-Sided Auction** Competition between Customers Competition between Providers
	MANY		**Combinatorial Double Auction** Allocation of Multi-Items Multiple Customers and Providers Involved
Notes: N represents number of customers, M represents number of providers			

Fig. 2-4. Taxonomy of Auction Design

An English auction is during the auction, the auctioneer announced an increase in the minimum starting price and auction target. Bidders start from the initial bid, from the lowest price to the highest price. However, the transaction price should be greater than the reserved price. This auction method got its name because it originated in England. England is a gentleman-civilized country. When the auction boomed, it became rich. Many rich people are willing to confirm their identity and strength in the auction. Such as antiques, artworks, ancient books, etc. The identity of the participants has a great influence on their "face psychology", the auction site is very fierce, the price increase is very large, and the characteristics of competitive price increases are obvious [112-115].

Dutch auctions are also called "low-price auctions" or "high-value auctions." This means that during the procedure, the auctioneer will announce the starting price and the price reduction of the auction target, and then the first bidder will end the transaction. As the same as English auction, the transaction price should be greater than the reserved price as well. The auction price of the auction target decreases a bidder’s bid wins (equal to or higher than the reserved price). Reduced-price auctions usually start at very high prices, prices are too high, and sometimes no one even bids. Currently, the price drops from a high price to a low price until the bidder is willing to accept it. If there are two or more bidders responding to the price at the same time, it will be converted into a price increase auction. In most reduced-price auctions, there are many bids. Because auctions often use reduced-price auctions when the quality is different, the first bidder with the highest bid can purchase all items, but usually only the best item can be purchased at the highest price. Then, the auction continued, and prices fell. When another bidder is willing to accept the bid, he also has the same choice, which is the best choice for the remaining choices, and then the auction will continue. In this case, although bidders remained silent most of the time, there was still constant competition among bidders [117-120].

A combination of British and Dutch auctions. This means that during the auction, after the auctioneer initiates the auctioning (i.e., the bidding price and the lowest price), the bidder will bid for the corresponding price, the auctioneer will increase the bidding price in turn, and the highest bidder will win. If no one bids, the auctioneer will lower the bid and the price, bid sequentially, and bid with the first bidder. Also, the transaction price should be greater than the reserved price [123-126].

Sealed-bid auctions are also called tender auctions. The buyer submits the sealed offer (also known as the bid) to the auctioneer within a specified time, and the auctioneer selects the buyer. Compared with the above two methods, the auction method has the following two characteristics: first, in addition to price conditions, other transaction conditions need to be considered; second, it can be open-bided. This method can be used when auctioning large facilities or large inventory items or items confiscated by the government [121-123].

Vickrey auctions, also known as second price sealed auctions. This auction method is basically the same as the first auction, except that the winner must pay the second highest price, not his own price. This is similar to the agency bidding system used by eBay. In this system, the winner needs to pay the second highest bid, plus a price increase (e.g., 10%). In practical applications, the Vickrey auction was accepted. For instance, the method of auctioning Treasury Bills in the United States has been adopted with. However, their rules allow the number of objects to be greater than one, and the number of bidders can exceed one. The rules are as follows: when bidders bid, they need to determine the required quantity and unit price. The seller ranks all bids based on the total bid amount (from high to low), gives priority to the highest bidder, and then determines the price as an allocation that does not meet the target 's highest bid. Because the bidder does not think that all bids have the same price, it is called the unit price method. The price is determined by the highest bid price without bidders, so it still retains the characteristics of the Vickrey auction, that is, everyone will bid based on their own real evaluation [116-120].

Combinatorial auction is a type of auction. It was proposed in 1982. It is different from traditional auctions. This is an auction method where bidders can bid on combinations of multiple commodities. It applies to the situation where the buyer does non-cumulative measurement of the value of the goods. Compared with traditional auctions, combinatorial auctions are more efficient when distributing multiple commodities. The target of this auction method is to gain various commodities. The buyer writes a combination of multiple commodities and the price of the combination, or the seller provides a different combination, and the buyer bids for the combination provided by the seller. This auction method increases the value of the combined items more effectively than a single auction [117, 118].

Reverse auctions, also known as auction purchases, are commonly used in government procurement and engineering procurement. The buyer provides information on the desired product, service needs and affordable price positioning, while the seller determines the final product provider and service provider in a competitive manner so that the buyer can get the best price / performance ratio. Reverse auction as a common auction method has the following characteristics: (1) Because the transaction rules of reverse auction are to win at a lower price, it can save costs for buyers; (2) It is said that the buyer 's purchase purpose is strong, and the transaction process is relatively simple and easy to control. (3) Since the reverse auction is conducted in accordance with certain rules, for the seller, fair competition among the sellers is guaranteed; (4) In the reverse auction process, the price determines who the buyer chooses to buy the goods from. Therefore, price is a key factor, and the seller 's product quality, reputation, etc. cannot be used as judgment criteria; (5) Since the seller is rational, the bid price cannot be lower than its cost value [120-122].

For instance, an English auction is a single-sided auction, whereas a combinatorial double auction is a double-sided auction. In a combinatorial double auction, sellers and buyers submit estimates for bundled objects. Providers have flexible chances to sell items to different customers; customers have more dynamic opportunities to purchase bundled items from different providers, just as they would expect. Depending on unique features of cloud computing, companies have the chance to employ different types of auction [127-129]. The following figure (Fig. 2-5) describes bidding directions of different types of auctions.

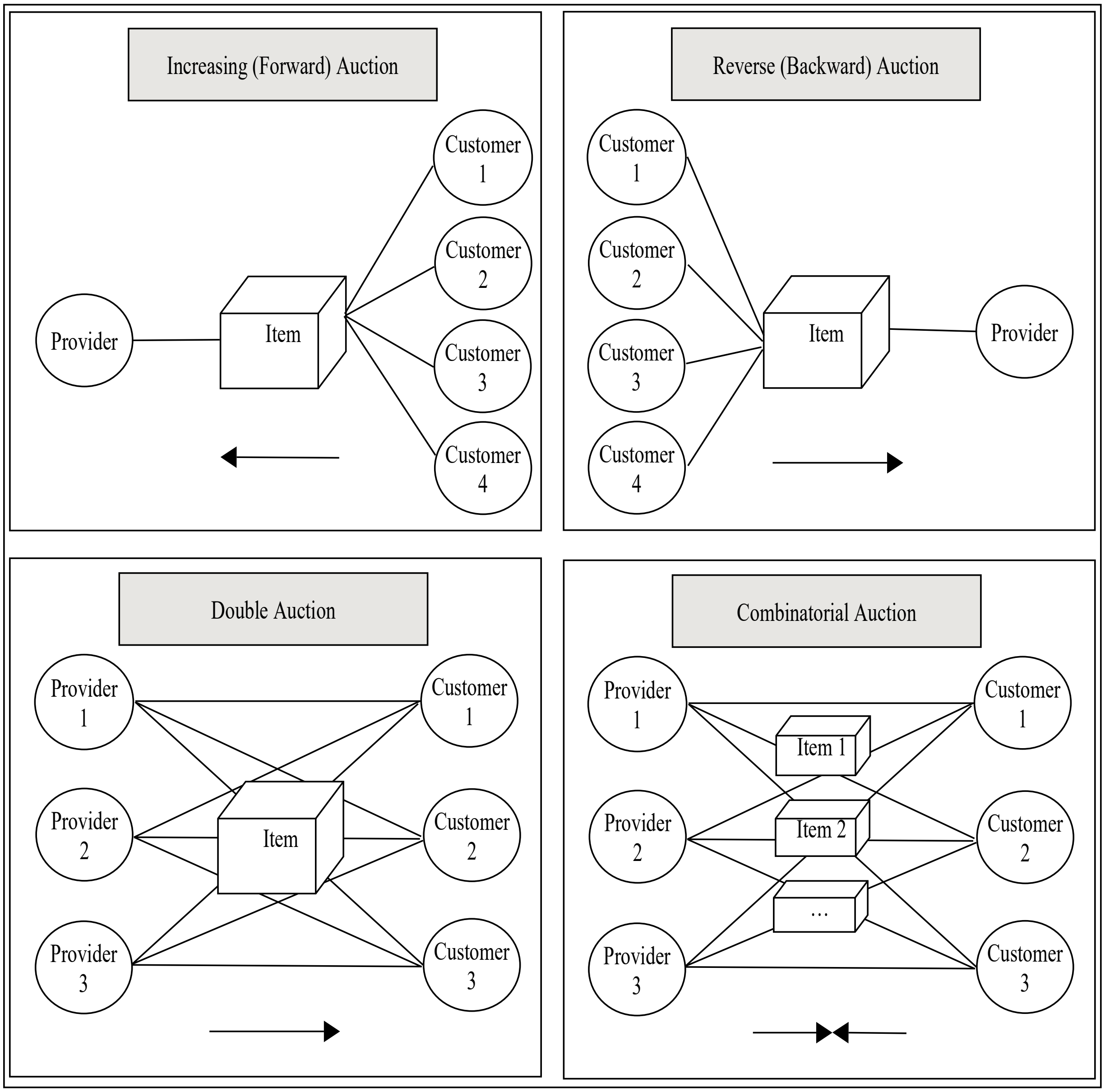

Fig. 2-5. Different Bidding Directions of Auctions

2.2.6 Conditions of auction design

In economics, an auction design could be perfect, such auction is able to achieve to three major criteria: Individual Rationality (IR), Budget Balance (BB), and Truthfulness (TF). However, in reality, it is so difficult to conduct all the three rules together because of there exist many different factors impact the ideal model to be true [130-132]. In this auction design, I focus on two requirements: Individual Rationality (IR) and Truthfulness (TF).

Individual Rationality (IR): All participants (provider and customer) are rational. In other words, each participant would seek some benefit through the procedure, otherwise, no participant wants to join the auction. For instance, customer i's bid should be greater than the marketing price (P), at least the two prices are equal: $B_i \geq P$. on the other side, the bidding price (P) should be greater than provider's estimation (B_j), to the most provider's bid equals to the marketing price: $P \geq B_j$. In practice, IR is a natural phenomenon that applicable to each unit in game theory [133-138]. Each participant has the incentive to act in an auction design, because of the potential nonnegative gains through bidding auction procedure.

$$B_i \geq P \geq B_j \tag{2-1}$$

Assumption 1:

$$B_j \geq B_{i^-}^t \tag{2-2}$$

Budget Constraints (BC): No customer would like to pay more than his affordability. In particular, the customer i's overall payment is below his budget constraints exactly. This threshold ensures that customer will obtain expected qualified cloud services with reasonable prices. Furthermore, different levels of customer budget constraints various requirements of QoS expectations. In other words, for customer, his objective is to seek the same level of qualified cloud services with a relative lower expense [139-143].

Truthfulness (TF): Truthfulness is also known as incentive compatibility (IC) or strategy-proof [144-146]. Based on Nash Equilibrium, each participant should report a truthful value (V) if he or she intend to optimize profits and utility. Otherwise, if some of the participants choose untruthfully bidding ($B_j \neq V_j$ or $B_i \neq V_i$), they will suffer potential losses. Truthfulness is critical in maintain a well-being environment in the cloud computing business: a trusted, fairness, and efficient market [147-149].

$$B_j = V_j \text{ and } B_i = V_i \tag{2-3}$$

2.3 Cloud Pricing Mechanisms

At present, fixed pricing strategies are widely used because of the simplicity and easy understanding. The adoption of dynamic pricing mechanism is still relatively small, mainly because its pricing mechanism is more complicated, but dynamic pricing mechanism can compensate the disadvantages of fixed pricing mechanism. For instance, dynamic pricing can present flexible prices based upon the marketing fluctuation (between supply and demand) and avoid potential loss caused by fixed pricing; meanwhile, dynamic pricing can reduce the trading price to balance customer's budget constraint. As the cloud industry continues to develop, the dynamic pricing mechanism will attract more and more participants' attention and meet with various requirements. The following table list some of popular cloud services from different companies using different types of pricing strategies (Table 2-4).

TABLE 2-4

Pricing Strategies of Cloud Services from Different Companies

Company	Services	Pricing Strategy	Functions
Amazon AWS	EC2 (Elastic Compute Cloud)/S3 (Simple Storage Service) /Aurora/	Free-of-charge Pay-per-use Subscription	Analytics/application integration/blockchain/ compute/customer engagement/Database/game

	DynamoDB/RDS/Lambda/VPC/ Lightsail/SageMaker	Spot Instance	tech/IoT/machine learning/media services/ networking/security/storage
Google App Engine	Application platform	Free-of-charge Pay-per-use Tiered pricing	Facilities/web application
IBM Cloud	Bare metal services/virtual servers/ object storage/Kubernetes service/ Cloudant/blockchain platform/ Waterson Assistant/Natural language understanding	Free-of-charge Pay-per-use Subscription	Analytics/application integration/blockchain/ compute/customer engagement/Database/game tech/IoT/machine learning/media services/ networking/security/storage
Microsoft Azure	Virtual machines/windows virtual desktop/SQL database/App service /Cosmoc DB/PlayFab/Kubernetes service/Functions/Cognitive services/Quantum	Pay-per-use Subscription	Analytics/application integration/blockchain/ compute/customer engagement/Database/game tech/IoT/machine learning/media services/ networking/security/storage

Other Companies	Akamai/Alibaba Cloud/Box.net/Linode/OpSource/Rackspace /SalesForce.com…

2.3.1 Fixed pricing strategy

There are many different types of fixed pricing: pay-per-use, subscription, unit pricing, and tiered pricing. Pay-per-use and subscription are the two main fixed pricing strategies adopted by companies (Table 2-5).

Today, cloud computing services mostly follow a very simple pricing scheme, offering fixed prices for various resource types. The fixed pricing strategy for different cloud services is mainly in one of three forms: pay per use, subscription, and tiered pricing [150]. Pay-per-use, which means that the customer pays a fixed price for the unit service used, typically gigabytes per hour or CPU per hour. Pay per use is typically used in the Infrastructure as a Service (IaaS) and Platform as a Service (PaaS) models. For instance, Amazon AWS and Google App Engine charge a fee of the service based on usage. Subscription refers to a pre-selected combination of service units that are used for a long time at a fixed price [151]. Customers subscribe (or sign contracts) and believe that in the subscription model, pricing is based on time rather than usage. In addition to pay per use, subscription is the most commonly used model for cloud service. Subscription is the most widely used pricing model for Software as a Service (SaaS). It allows customers to predict the periodic cost of their use of cloud services, and customers can use the service by paying an annual or monthly fee [152]. In cloud computing, tiered pricing mainly refers to providers offer multiple levels of services. Each level has certain technological specifications (e.g., storage, geographical location, memory, CPU power, elasticity, security, etc.) and service level agreements (SLAs). Customers can choose certain level of service to buy according to their needs. Amazon AWS also adopts tiered pricing strategy. Amazon.com sells a variety of different types of specifications. Each is packaged into a different storage and memory format. Customers can purchase different specifications as needed [49], [153].

TABLE 2-5

Comparison of The Four Major Fixed Pricing Strategies

Pricing Strategy	Features	Type of Cloud Resources	Companies
Pay-per-use	Consumers pay for the resources they use based on fixed-use units without long-term commitments.	IaaS, PaaS, SaaS	Amazon AWS, Google App Engine, Microsoft Azure, IBM Cloud
Subscription	Consumers pay a certain amount of service up front and get discounts and lower prices from use.	IaaS, PaaS, SaaS	Amazon AWS, Google App Engine, Microsoft Azure, IBM Cloud
Tiered Pricing	Multiple levels of services	IaaS, PaaS, SaaS	Amazon AWS, Google App Engine, Microsoft Azure, IBM Cloud
Free-of-charge	There are no fees for certain services. Customer can use the services for a certain time period with no payment.	IaaS, PaaS, SaaS	Amazon AWS, Google App Engine, Microsoft Azure, IBM Cloud

2.3.2 Dynamic pricing strategy

By adopting a dynamic pricing strategy, suppliers can flexibly modify prices according to fluctuations in the market. If the modified price is lower than the fixed price, more customers will be attracted since they can get the same service at a lower cost. This will increase provider revenue. If the modified price is higher than the fixed price, the provider will also receive more revenue due to the higher payment of each service. It is recommended to use a dynamic pricing scheme to price the federated cloud resources to compensate the deficits, which are caused by the fixed pricing algorithm, for both provider and customer based on supply and demand [40]. Hence, dynamic pricing strategies are more flexible and reasonable than fixed pricing strategies. It can allocate available cloud resources to meet customer needs and balance customer budget constraints (Table 2-6). Compared to the fixed pricing strategy, the advantage of dynamic pricing strategy is to adjust price flexibly based on marketing conditions, especially the relation between supply and demand. By this way, for providers, they can change price consistently according the supply and demand; for customers, they have a great chance obtain the same QoS level of cloud services but paying less [155-157].

TABLE 2-6

Dynamic Pricing Strategies

Pricing Mechanism	Pricing Objective and Explanations	Article
Genetic Model	Cloud Market and Pricing Three steps: define, evaluate, and select the best pairs of chromosomes. Genetic model is better than some dynamic models and fixed pricing mechanisms.	[109]

Dynamic Pricing Scheme	Compensating the deficits For the federated cloud resources to compensate the deficits based on supply and demand. Benefit to both providers and customers.	[154]
Markov Decision Process	Formulating the competition Among providers, seeking more appropriate mechanisms to allocate cloud resources.	[158]
Model Predictive Control Theory	Dynamic resource allocation Dynamically and effectively adjusting prices for available cloud resources.	[159]
Financial Option Theory	Providing high QoS Tracking real values of cloud resources to guarantee high QoS for customers expectation and providers overall quality performance.	[60]
Optimal Capacity Control	Revenue optimization Especially for providers to maximize revenues under uncertainties and incomplete information.	[161]

2.3.3 Bidding pricing strategy

Applying economics game theory to price cloud services is a reasonable choice. Price fluctuations can reflect the relationship between supply and demand in real time, providing incentives and constraints for users to rationally choose resources. At the same time, the service price can be used as the basis of resource allocation to realize service differentiation [162-164].

The following table (Table 2-7) addresses the extant study using auction design to pricing available cloud resources.

TABLE 2-7

Different Types of Auction Design

Type	Pricing Objective	Article
English Auction	Maximizing provider's revenue and shortening the execution time, also solve NP-hardness.	[165] [166]
Dynamic Auction	Coping with changes in cloud market, such as Asymptotic optimization, incentive compatibility, and computational complexity are integrated to allocate available cloud resources.	[167-169]
Marginal Bidding	Truthfulness and dynamic adjustment mechanisms to generate revenues for providers.	[170] [171]
Double Auction Bayesian Model	This framework enables multiple customers to purchase services from multiple providers. The mechanism helps customers purchase cloud resources flexibly.	[172-174]
Double-Sided Combination Auction and K-Pricing Scheme	This mechanism is suitable for cases requiring various services and where many participants exist. A double-sided auction model and K-pricing scheme were used in this mechanism.	[175-177]

Auction-Greedy Design	An auction design is better than the fixed-price mechanism. Furthermore, a greedy algorithm generates more revenues than a linear programming.	[178-181]
Combinatorial Double Auction	The economic efficiency of the cloud resources and allocation is more important to providers.	[182-185]

2.3.4 Amazon AWS EC2 (Elastic Compute Cloud) Spot Instance

"Amazon EC2 Spot instances are free computing power available in AWS services. Compared with the price of on-demand instances, such instances can provide extra discounts. EC2 Spot can help you optimize the cost of AWS services, and can increase application throughput by 10 times without changing the budget. You only need to select "Spot" when launching an EC2 instance to save 90% of the on-demand instance price. The only difference between an on-demand instance and an auction instance is that when EC2 needs more capacity, it will issue a two-minute notification and then interrupt the auction instance. You can use EC2 Spot for a variety of fault-tolerant and flexible applications, such as test and development environments, stateless web servers, image rendering, and video transcoding to run analytics, machine learning, and high-performance computing (HPC) workloads. EC2 Spot can also be tightly integrated with other AWS products, including EMR, Auto Scaling, Elastic Container Service (ECS), CloudFormation, etc. Offering you the flexibility to choose how to start and maintain applications running on Spot instances"[6] [186-195]. Amazon.com is the first company that implements an auction-like pricing strategy to cloud services [196-201]. Many scholars and

[6] https://aws.amazon.com/ec2/pricing/

practitioners are attempting to find some clues about how Amazon price the available cloud resources by Spot Instances (Table 2-8).

Amazon AWS disclose Spot Instance pricing data each three month. Based on the historical data, scholars try to decode and illustrate Amazon's dynamic pricing processes. The following table summarizes the relevant studies. A study indicates that Amazon AWS Spot Instance is one of pricing strategies that offer dynamically changing prices based on market changing conditions [202-204]. Wang, et al [205] proposed a specific model Lyapunov Optimization as a future pricing strategy for Spot Instance. Singh and Dutta [209] used Mean absolute percentage error (MAPE) to predict dynamic changes of Amazon Spot Instances. Zhang, et al. [212] constructed predictive control theory for spot markets to resource allocation in cloud computing environment. Wallace, et al. [215] adopted with Neural Network to predict the spot prices.

TABLE 2-8

Amazon AWS Spot Instance Study

Pricing Mechanism	Pricing Objective	Article
Finite Horizon Formulation and Sensitivity Analysis	Revenue maximization	[202-204]
Lyapunov Optimization	Revenue Optimization	[205-208]
Mean Absolute Percentage Error (MAPE)	Dynamic price prediction	[209-211]

Model Predictive Control Theory	Dynamic resource allocation	[212-214]
Deep Learning Algorithm (Neural Network)	Decoding and illustrating the functionality of Spot Instance	[215-218]

2.4 Unsolved Issues from the Extant Cloud Pricing Strategy

2.4.1 Issues of Fixed Pricing Strategy.

(1) Vague relation between supply and demand. Cloud price fluctuated instantly based on the changing market condition; in other words, price is an indicator of marketing condition. However, fixed price cannot express the holistic picture of price changing trend.

(2) Potential revenue loss. If a provider employs the fixed pricing strategy all the time, the price cannot be modified according to supply and demand. For instance, if the marketing price is lower than the fixed price, customers may choose other provider's services because that provider offers lower price that is suit for customers' budget constraints; if the marketing price is higher than the fixed price, the provider who employs fixed pricing strategy cannot change price easily. These two situations will lead to potential losses.

(3) Resource allocation is difficult to be optimized. Since price won't change instantly and dynamically, available cloud resources have great chance not to allocate to customers due to fixed pricing strategy. Hence, provider won't optimize revenues [59, 60].

2.4.2 Quality of Service (QoS) of Cloud Computing

Cloud service is the main form of cloud computing, and the quality of service is the overall performance of cloud computing. Cloud QoS is defined as "the overall effect of users using cloud computing services. These effects determine user satisfaction.[7]" The quality of cloud services reflects whether cloud services meet Yonghua's expectations and whether user interests are guaranteed. The SLA clarifies the rights and responsibilities and establishes participants' trust in cloud business [219, 220].

Based on the existing pricing mechanisms, both participants are difficult to seek clues that guarantee expected QoS performance, especially to customers. As indicated in Figure 2-6, many critics are critical to QoS performance. Such as availability, reliability, latency, security, throughput, capacity, scalability, elasticity, service & help, cost per customer, etc. In this thesis, I proposed a model that includes QoS parameters, availability and response time, to estimate the value of cloud resources. It is easy for participants to get a reserved price from the model [221, 222].

Customers have their own needs and expectations of computing services, they will refer to the cloud service functions and prices of different providers when choosing providers and the corresponding services, and strive to balance demand, expectations and costs. Hence, for providers, QoS is a critical method to value service performance from perspectives of technology and customer satisfaction. Providers can provide different service quality and service levels to help meet the different levels of service needs of customers [223-225].

QoS has different explanations from different angles. Based on the usage of cloud services, QoS can be considered as customer expectation and provider guarantee; after providers offer cloud resources, QoS can be treated as customer recognition and provider accomplishment. Because the proposed hybrid pricing mechanism is constructed for purchasing cloud services,

---

[7] ITU-T Recommendation E.800. Definitions of Terms Related to Quality of Service [G]. Quality of Telecommunication Services: Concepts, Models, Objectives and Dependability Planning? – Terms and Definitions Related to the Quality of Telecommunication Services. ITU-T Study Group, 2008.

QoS from customer expectation and of provider guarantee are considered in the thesis [226, 227].

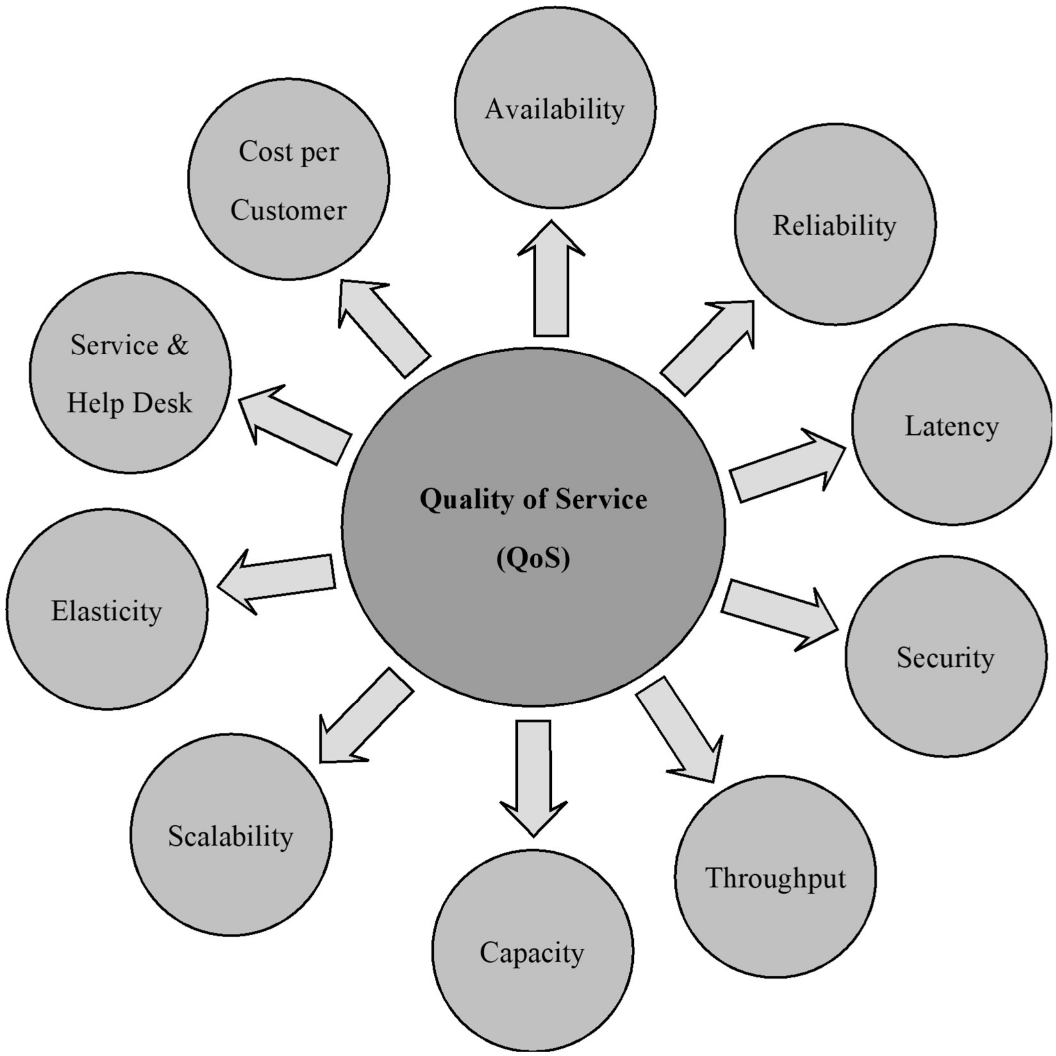

Fig. 2-6. Critical QoS Metrics of Cloud Services

The cloud computing QoS is an expression about the level of cloud computing service quality required by customers and indicates the degree of demand of customers for a certain QoS service. Customers do not care about the details of service provision and design, but care about the effectiveness and QoS. When describing QoS requirements, customers can use non-technical language to express. These requirements are very important to providers. Providers need to design services from the perspective of customers QoS preferences. Providers define the customers' QoS requirements based on customers' description of QoS and promise to guarantee QoS by SLA (Service Level Agreement) [228].

QoS of cloud computing provided by providers represents the quality level that providers plan to provision to customers. Providers use specific technical measurement parameters to represent the QoS level that customers require. Each service has a unique QoS parameter set. The QoS parameter sets of different services have different indicators, which are used to represent different targeted values, ranges and levels. Providers should have two expressions for QoS. One is for customer QoS using non-technical or non-professional language. The other is the technical or professional expression used by providers internally [228, 229]. The following picture (Fig. 2-7) indicates the relation between customer expected QoS and provider guarantee QoS.

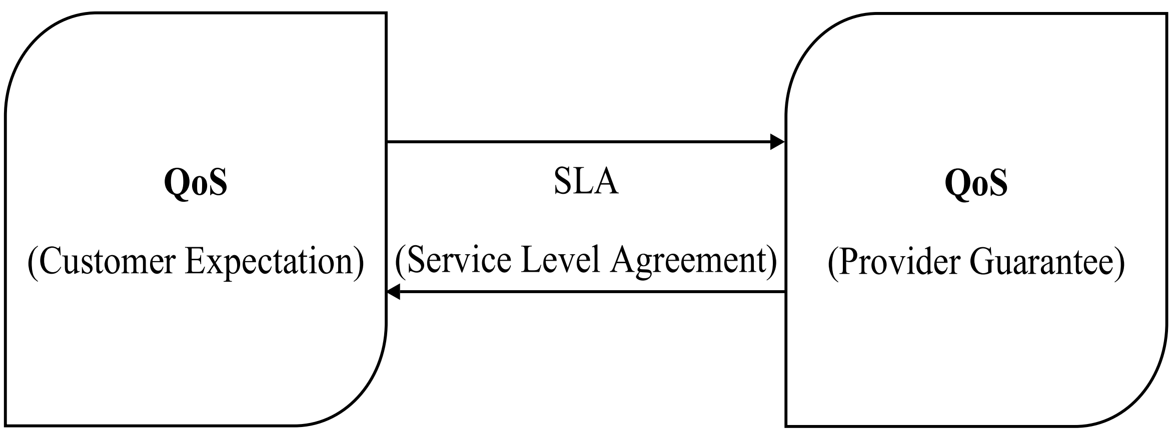

Fig. 2-7. SLA between Customer' and Provider' QoS

The goal of cloud resources is to fulfill the requirements of customers and services at any time and provide on-demand services to customers. But this is not an easy task. For providers, the technical guarantee of cloud computing QoS still faces huge challenges. Cloud resource can be treated as a normal good with unique QoS parameters [227-230].

CHAPTER 3

QOS-BASED HYBRID PRICING STRATEGY

This chapter is dedicated to proposing QoS-based pricing model.

Current pricing methods are based on fixed pricing strategies. Fixed pricing is simple, and buyers are easy to follow and accept. The problems are (1) the price of a resource cannot be dynamically modified based on resource usage between supply and demand. Although some major companies adopt bidding or dynamic pricing strategies for certain services, it is still difficult to understand how the companies price the resources. It is argued that companies priced resources based on traditional methodologies not dynamic pricing strategies. (2) cloud providers will suffer potential revenue loss due to more potential customers will be involved and price will be fluctuated along with the fixed price.

In order to improve the market competitiveness of providers and offset the weakness of fixed pricing strategy in cloud computing, on the basis of different QoS requirements from customers, I proposed a hybrid QoS-based pricing mechanism that executes both fixed pricing strategy (e.g., subscription) and dynamic pricing strategy (e.g., optimal auction design) to calculate a reserved price for participants (providers and customers) and to allocate resources among customers effectively and efficiently. Afterwards, the hybrid pricing mechanism has the potential to help providers attract more customers with relatively lower price and gain more revenues. Specifically, when the cost of cloud resource is higher than the marketing price in cloud market, a fixed subscription price strategy will be adopted; when the marketing price is higher than the cost of cloud resource but lower than the fixed price of cloud resource, a dynamic auction design will be implemented; when the marketing price is higher than the fixed price of cloud resource but lower than the equilibrium price of cloud resource (when supply equals to demand), a dynamic auction design will be implemented. Overall, the hybrid pricing mechanism is able to explore both the two pricing strategies' advantages and to provide supplier and customer expected benefits [231, 232].

It is generally believed that an appropriate price mechanism is an effective way to better allocate available cloud resource. The QoS level and performance of the cloud services obtained is directly related to the expenses a customer needs to pay. If the same amount of cloud services is used, the higher the performance or the higher QoS level of cloud services a customer requires, the higher prices of the related cloud services will be [233, 234]. What the customer pays depends on the price of the service conducted by cloud provider as well. The QoS-based pricing model can reflect the needs of both providers and customers. Specifically, differentiated QoS threshold represents different prices to cloud services. Different prices reflect the QoS differences of the resources required by different customers, making the relationship between price and QoS more reasonable [235,236]. The price itself reflects the customer's preference for QoS. For the provider, the corresponding high-quality service can be provided according to the different requirements of the customers' QoS. It will be attracting more potential customers and achieving higher profits. In this section, we address the issue of designing a novel hybrid pricing mechanism that consists of fixed pricing strategy (subscription) and dynamic pricing strategy (optimal auction design) as an advanced pricing mechanism through which cloud services are priced, paired, and allocated [237-239].

With abundant resources, depending on customer expectation on different QoS expectations for cloud services, customer budget constraints, and actual cloud service usage, we explore performance estimation and quality sensitivity pricing mechanism (hybrid QoS-based pricing strategy) to make price setting and resource allocation more acceptable and reasonable [239, 240].

3.1 Developing Stages of Cloud Industry

This section depicts the three development stages before the cloud market turns to be mature. The details are described in figure 3-1. The proposed context is applicable to different types of cloud companies and providers, such as large, medium, and small companies. Suppose that in the market, supply is stable for all the time. In other words, all available cloud resources from different providers can fulfill all customers' demand. And, demand from customers will be increasing from the initiating to maturing stage. The details are illustrated and explained in the following (Fig. 3-1).

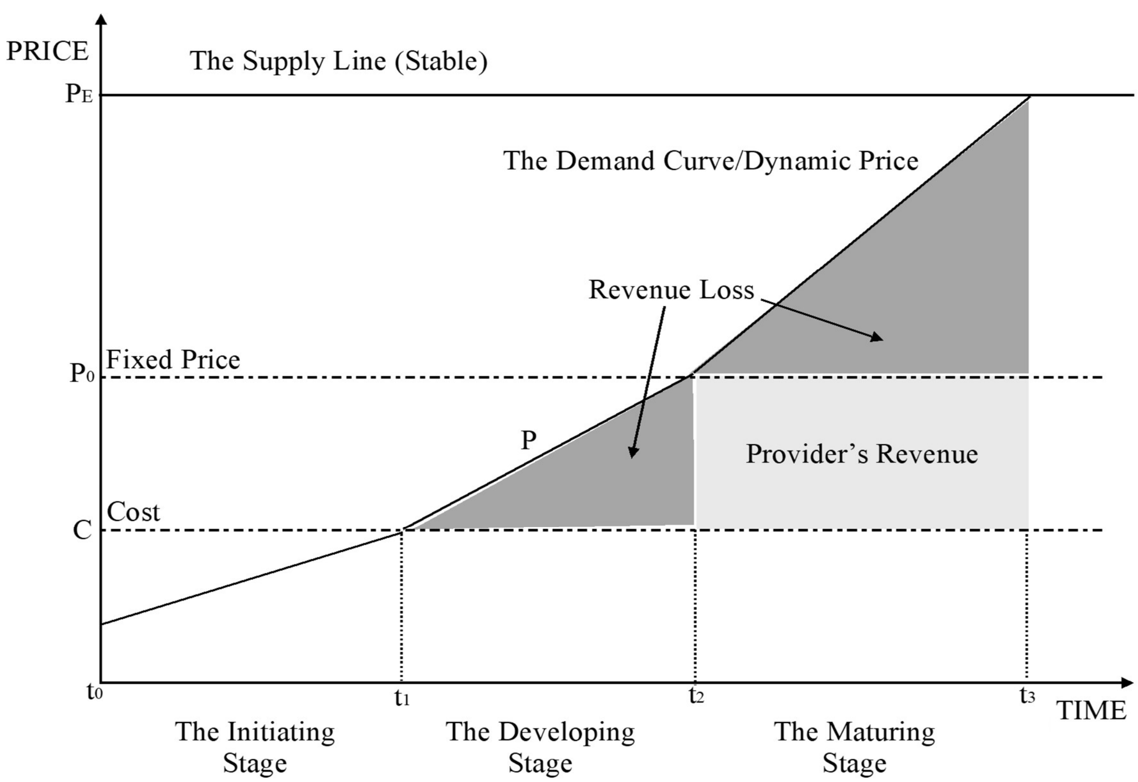

Fig. 3-1. Different Developing Periods of Cloud Industry

3.1.1 The Initiating Stage

The initiating stage is between $t_0 \sim t_1$. And the marketing price (P) is lower than the cost of cloud resource (C). In the market, there are only a few customers with plenty of cloud resources from multiple providers. This stage is not a good time for companies to gain revenues, but to attract potential customers. Also, it is not necessary to change the price instantly. A better pricing strategy for company to adopt with is to offer customers discount or promotional price. An example is Amazon AWS who offers customers free-of-charge for certain cloud services for one year.

In the initiating stage, subscription (fixed pricing strategy) is used to present reserved price for both providers and customers. Subscription is a better pricing strategy than pay-per-use. For providers, they can offer lower price to attract more potential customers; for customers, they can obtain expected cloud resources within their budget constraints. The initiating stage is the early development of a cloud-relevant company, it is a good time for a company to improve its performance of cloud services and to develop its operational activities in the cloud market. It is the time period when customers begin to recognize cloud computing and start to use some certain resources with only limited payment. The mathematical proof is described in Chapter 4.

3.1.2 The Developing Stage

The developing stage is between $t_1 \sim t_2$. And the marketing price (P) is lower than the fixed price of cloud resource (P_0) but higher than the cost of cloud resource (C). In the market, the quantity of customers will be increasing, due to the growth of cloud marketing. This stage is the first time for companies start to gain revenues. But, if a company adopts with the fixed pricing strategy, it may encounter potential revenue loss that expressed in Figure 3-1. Hence, it is better for a company to seek to change the price instantly. A better pricing strategy for company to adopt with is to offer customers dynamic price. The price will be modified based on marketing fluctuation between supply and demand. For a certain customer's resources, a provider offers a lower price, a lower price based on supply and demand will attract more customers to purchase cloud resources, leading to the economies of scale. Companies will obtain more revenues overall eventually. An example is Amazon AWS who offers customers Spot Instance for certain cloud services.

In the developing stage, a double auction design (dynamic bidding pricing strategy) is used to present reserved price and bidding procedures for both providers and customers. Auction design is a better pricing strategy than fixed pricing strategy. For providers, they can offer flexible-changing price to attract more potential customers; for customers, they can obtain expected cloud resources within their budget constraints. Specifically, a dynamic auction design is potential to avoid revenue loss in this stage, if more customers would like to be involved in the auction process to bid for cloud services. They can obtain high level of QoS-guaranteed cloud services, but to pay less compared to a fixed pricing strategy. Providers would continue to improve the overall QoS performance to hold the market share. The mathematical proof is described in Chapter 4.

3.1.3 The Maturing Stage

The maturing stage is between $t_2 \sim t_3$. And the marketing price (P) is lower than the equilibrium price of cloud resource (P_E) but higher than the fixed price of cloud resource (P_0). In the market, the quantity of customers will be increasing, due to the growth of cloud marketing. This stage is the good period for companies to gain revenues. But, if a company adopts with the fixed pricing strategy, it may encounter potential revenue loss that expressed in Figure 3-1. Hence, it is better for a company to seek to change the price instantly. A better pricing strategy for company to adopt with is to offer customers dynamic price. The price will be modified based on marketing fluctuation between supply and demand. An example is Amazon AWS who offers customers Spot Instance for certain cloud services.

In the maturing stage, a double auction design (dynamic bidding pricing strategy) is used to present reserved price for both providers and customers. Auction design is a better pricing strategy than fixed pricing strategy. For providers, they can offer flexible-changing price to attract more potential customers; for customers, they can obtain expected cloud resources with paying reasonable expenses. In this stage, the number of customers and companies will continue to increase. Both customers and providers encounter more challenges. A dynamic auction design is potential to leverage both parties' risks and balance budget constraints and QoS expectations. The mathematical proof is described in Chapter 4. The following table (Table 3-1) addresses detailed pricing strategies for the three development stages.

TABLE 3-1

Developing Stages and Pricing Strategies

Developing Stage	Time Period	Customer Quantity	Pricing Strategy	Price Scope
Initiating	$t_0 \sim t_1$	Only A Few	Subscription	P < C
Developing	$t_1 \sim t_2$	Increasing	Dynamic Auction Design	C < P < P_0

Maturing	$t_2 \sim t_3$	A Lot Of	Dynamic Auction Design	$P_0 < \mathrm{P} < P_E$

3.2 Quality of Service (QoS) of Cloud Pricing

3.2.1 The Relation between QoS Metrics and Price

The QoS metrics (X) is consisting of availability ($A_{(x)}$), elasticity (E_x), reliability (R_x), security (S_x), etc. The bidding price is based on the reserved price (P_R) that is applicable to both seller and buyer. x refers to all possible features that influence the performance of QoS in cloud computing, such as CPU power, speed, storage, location, etc.

The QoS metrics (X):

X

A (Availability), A_x

E (Elasticity), E_x

R (Reliability), R_x

S (Security), S_x

…

The function that expresses the reserved price is:

$$P_R = F(X) = F(A_x, E_x, R_x, S_x, \dots) \tag{3-1}$$

3.2.2 An Example of Relation between Availability and Price

The availability of cloud computing is one crucial QoS parameter, but it is difficult to quantifiably analyze, because cloud services are implemented through the entire serving process in a complicated network that integrates software, hardware, and the related computing techniques. Availability[8] represents the percentile of the uptime of cloud services [68-70]. Better performance of cloud services is intimately related to higher level of availability. A more stable system will decrease the number of failures and will lessen the time spent in repairing.

The relationship between availability and Uptime and Downtime is

$$A = \frac{MTBF}{MTBF+MTTR} = \frac{Uptime}{Uptime+Downtime} \tag{3-2}$$

A refers to availability. MTBF (Uptime) and MTTR (Downtime) are the two parameters of cloud computing. MTBF is the Mean Time between Failure, and MTTR is the Mean Time to Repair [227-232]. Thus, based on the above function, the availability can be increased either by increasing the mean time interval between repairs (MTBF) or by decreasing the mean repairing time (MTTR). The intuitive way to represent availability is by using the downtime and the Nines and Fives, e.g., 2 Nines is 99% and 3N5 is 99.95%. The following table (Table 3-2) is an example.

TABLE 3-2

Representation of Availability

Availability	Downtime
99% (2-Nines)	3.65 days/year
99.5% (2N5)	1.825 days/year
99.9% (3-Nines)	8.76 hours/year
99.95% (3N5)	4.38 hours/year
99.99% (4-Nines)	52 minutes/year

[8] The probability that the system will be up and will function correctly in a certain time period.

99.995% (4N5)	26 minutes/year
99.999% (5-Nines)	5 minutes/year

Ideally, different QoS indicators can be integrated into the price function. The following model is an example relation between availability ($A_{(x)}$) and the reserved price (P_R).

The function that expresses the availability is:

$$A_{(x)} = g(x) \tag{3-3}$$

The function that expresses the reserved price is:

$$P_R = f(A_{(x)}) \tag{3-4}$$

3.2.3 The Relation between Response Time and Price

Suppose at time t, customer agent submits a request of Q_i, the workload of provider j is

$$Load_j^t = \frac{ResUsed_j^t}{ResMax_j} \tag{3-5}$$

$ResUsed_j^t$ is the total number of other accepted resource requests between time t and the deadline, $ResMax_j$ is the maximum of resources that provider j can provide.

Suppose that provider can fulfill all the accepted customers' requests. The asking price (Ask_j^t) is proportional to the current workload ($Load_j^t$). That is, as $Load_j^t$ increases, Ask_j^t also increases; vice versa. The expression is as follows,

$$Ask_j^t = AskREV_j \times (1 + {Load_j^t}^{\alpha}) \tag{3-6}$$

α indicates the degree of impact of the workload on the asking price. It satisfied that $0 \leq \alpha \leq 1$.

Suppose that all the accepted customers' requests can be provided before the deadline. The bidding price (Bid_i^t) is proportional to the current workload ($Respond_i^t$). That is, as $Respond_i^t$ increases, Bid_i^t also increases; vice versa. The expression is as follows,

$$Bid_i^t = BidREV_i \times (1 + (\frac{Respond_i^t}{ResMax_j})^{\beta}) \tag{3-7}$$

$Respond_i^t$ is the respond time of Q_i, which is a dynamic value. $Respond_i^t$ = the current system time – the submission time of Q_i. After Q_i is allocated to customer, $Respond_i^t$ will be kept unchanged. β indicates the degree of impact of the time on the bidding price. It satisfied that $0 \leq \beta \leq 1$. At time t, the customer submits the service request (Q_i) and the bidding price (Bid_i^t).

In the auctioning procedure, the asking prices are sorted in ascending order and the bidding prices are sorted in descending order. If the maximal bidding price is greater or at least equal to the minimal asking price, trading between customer and provider happens. The trading price (P) is the mean of the maximal bidding price and the minimal asking price. Such as,

$$P = \frac{1}{2}(Bid_i^t + Ask_j^t) \tag{3-8}$$

The hybrid pricing mechanism is formalized as follows:

Price Function	Pricing Strategy	Stages
	Subscription	Initiating
$P = \frac{1}{2}(Bid_i^t + Ask_j^t)$	Double Auction	Developing
	Double Auction	Maturing

CHAPTER 4

QOS-BASED CLOUD PRICING MODEL

This chapter is dedicated to describing the hybrid QoS-based pricing procedure.

Depending on the customer's different requirements for cloud services, suppliers need a viable and efficient pricing mechanism that is critical to the allocation and optimization of the available cloud resources. For suppliers, customers will bid for their own budget for better service, and the suppliers will select customers based on their bids, provide resources for higher-priced customers and guarantee the cloud’s QoS (Fig. 4-1). For customers, they can freely choose resources according to their own needs. However, due to the liquidity of marginal customers, whose bidding is uncertain, and it is difficult to estimate the demand based on existing bids. Hence, the cloud resource scheme based on uncertain bid auction has the potential to improve both system efficiency and optimal profits.

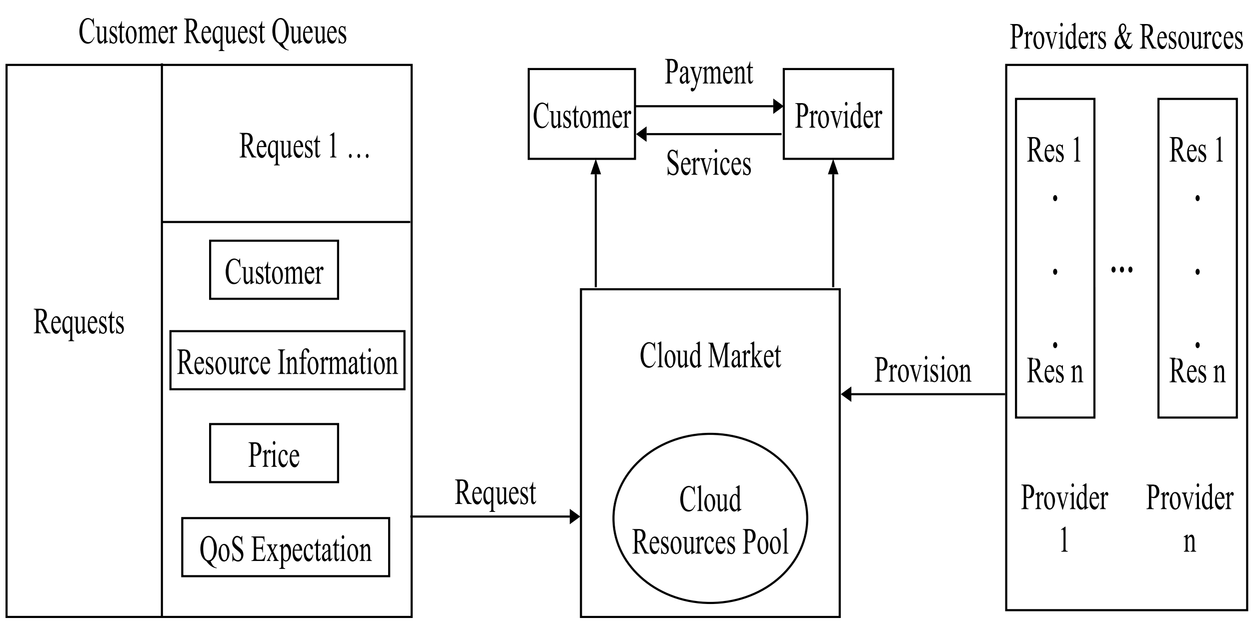

Fig. 4-1. Transaction of Cloud Allocation and Pricing

4.1 Subscription for The Initiating Stage

4.1.1 Problem Statement

Mathematical Proof of Subscription and Pay-per-use

The fixed price: P_0

The cost of service: C

The Price when demand is high: $P_{(D+)}$

The Price when demand is low: $P_{(D-)}$

Customer Consumption level when demand is high: X_i^{D+}

Customer Consumption level when demand is low: X_i^{D-}

Customer Maximal Consumption level when demand is high: $X_{(i,D+)}^{MAX}$

Customer Maximal Consumption level when demand is low: $X_{(i,D-)}^{MAX}$

Customer Utility Function: $U_i(X_i^{D+},\ X_i^{D-})$

Customer Optimization:

$$\max_{X_i^{D+},\, X_i^{D-},\, P_0} U_i(X_i^{D+},\ X_i^{D-}) - P_{(D+)}X_i^{D+} - P_{(D-)}X_i^{D-} — P_0 \tag{4-1}$$

$$\text{s.t. } X_i^{D+} \leq X_{(i,D+)}^{MAX},\ X_i^{D-} \leq X_{(i,D-)}^{MAX} \tag{4-2}$$

$$U_i(X_i^{D+},\ X_i^{D-}) - P_{(D+)}X_i^{D+} - P_{(D-)}X_i^{D-} - P_0 \geq 0$$

4.1.2 Provider Optimization

Considering consumer optimization issues, cloud service providers will adopt appropriate pricing mechanisms to maximize their own profits. Assume that the marginal cost of the services provided by the cloud service provider is zero.

$$X_i^{*} = X_i^{D+}(P_{(D+)}, P_{(D-)}, P_0) \tag{4-3}$$

$$X_i^{\#} = X_i^{D-}(P_{(D+)}, P_{(D-)}, P_0) \tag{4-4}$$

$$\max_{P_0, P_{(D+)}, P_{(D-)}} \sum_i (P_{(D+)} X_i^{*} + P_{(D-)} X_i^{\#} + P_0) - C \tag{4-5}$$

Where $(X_i^{*}, X_i^{\#})$ = argmax $[U_i(X_i^{D+},\ X_i^{D-}) - P_{(D+)} X_i^{D+} - P_{(D-)} X_i^{D-} - P_0]$ (4-6)

$$\text{s.t. } X_i^{D+} \leq X_{(i,D+)}^{MAX}, X_i^{D-} \leq X_{(i,D-)}^{MAX} \tag{4-7}$$

$$U_i(X_i^{D+},\ X_i^{D-}) - P_{(D+)} X_i^{D+} - P_{(D-)} X_i^{D-} - P_0 \geq 0$$

$$\sum_i (P_{(D+)} X_i^{*} + P_{(D-)} X_i^{\#} + P_0) - C \geq 0$$

4.1.3 Customer Optimization

$$\max_{P_0, P_{(D+)}, P_{(D-)}} \sum_i (P_{(D+)} X_i^{*} + P_{(D-)} X_i^{\#} + P_0) - C \tag{4-8}$$

Where $(X_i^{*}, X_i^{\#})$ = argmax $[\mathrm{a} \log(\mathrm{X} + 1) + \mathrm{b} \log(\mathrm{Y} + 1) - P_{(D+)} X_i^{D+} - P_{(D-)} X_i^{D-} - P_0]$ (4-9)

$$\text{s.t. } X_i^{D+} \leq X_{(i,D+)}^{MAX}, X_i^{D-} \leq X_{(i,D-)}^{MAX} \tag{4-10}$$

$$\mathrm{a} * \log(\mathrm{X} + 1) + \mathrm{b} * \log(\mathrm{Y} + 1) - P_{(D+)} X_i^{D+} - P_{(D-)} X_i^{D-} - P_0 \geq 0$$

$$\sum_i (P_{(D+)} X_i^{*} + P_{(D-)} X_i^{\#} + P_0) - C \geq 0$$

4.1.4 The Analysis of Different Types of Customer

The Homogeneous Customer

According to Cobb-Douglas Utility Function U (X, Y) = a log (X+1) + b log(Y+1)

When customer demand is 0, and customer utility is 0 but not negative infinity[9].

Customer Optimization:

$$\max_{X_i^{D+},\, X_i^{D-}} \text{a log (X + 1) + b log(Y + 1)} - P_{(D+)}X_i^{D+} - P_{(D-)}X_i^{D-} — P_0 \tag{4-11}$$

$$\text{s.t. } X_i^{D+} \leq X_{(i,D+)}^{MAX},\ X_i^{D-} \leq X_{(i,D-)}^{MAX} \tag{4-12}$$

$$\text{a log (X + 1) + b log(Y + 1)} - P_{(D+)}X_i^{D+} - P_{(D-)}X_i^{D-} - P_0 \geq 0$$

Provider Optimization:

$$\max_{P_0, P_{(D+)}, P_{(D-)}} \sum_i (P_{(D+)}X_i^* + P_{(D-)}X_i^\# + P_0) - C \tag{4-13}$$

$$\text{Where } (X_i^*, X_i^\#) = \text{argmax } [U_i(X_i^{D+},\ X_i^{D-}) - P_{(D+)}X_i^{D+} - P_{(D-)}X_i^{D-} - P_0] \tag{4-14}$$

$$\text{s.t. } X_i^{D+} \leq X_{(i,D+)}^{MAX},\ X_i^{D-} \leq X_{(i,D-)}^{MAX} \tag{4-15}$$

$$U_i(X_i^{D+},\ X_i^{D-}) - P_{(D+)}X_i^{D+} - P_{(D-)}X_i^{D-} - P_0 \geq 0$$

$$\sum_i (P_{(D+)}X_i^* + P_{(D-)}X_i^\# + P_0) - C \geq 0$$

Proposition 1.

[9] This not only simplifies the solution, but also explores how the utility function of homogeneous and heterogeneous customers (marginal utility is gradually decreasing) impacts on the choice of provider's pricing strategy.

If provider adopts with pay-per-use, the optimal price $P_{(D+)} = \frac{a}{X_{(i,D+)}^{MAX}+1}$ and $P_{(D-)} = \frac{b}{X_{(i,D-)}^{MAX}+1}$. And the optimal profit is: $\sum_i \left(a - \frac{a}{X_{(i,D+)}^{MAX}+1} + b - \frac{b}{X_{(i,D-)}^{MAX}+1}\right) - C = \sum_i [a\left(1 - \frac{1}{X_{(i,D+)}^{MAX}+1}\right) + b(1 - \frac{1}{X_{(i,D-)}^{MAX}+1})] - C.$

Proposition 2.

If provider adopts with subscription, the optimal price is $\mathrm{alog}\left(X_{(i,D+)}^{MAX} + 1\right) + b\log X_{(i,D-)}^{MAX} + 1)$. And the optimal profit is: $\sum_i [\mathrm{alog}\left(X_{(i,D+)}^{MAX} + 1\right) + b\log(X_{(i,D-)}^{MAX} + 1)] - C.$

The Heterogeneous Customer

Heterogeneous customers are divided into two categories. The one is divided into luxury customer and poor customer according to the budget constraint (willingness to pay/afford). The other category is divided into high-demand customers and low-demand customers.

I. Luxury and Poor Customers

Assuming that there are *d* luxury customers (i = 1) and *g* poor customers (i = 2), it focuses on whether different level of budget constraint impacts the provider's pricing strategy. Suppose the two categories of customers have the same consumption upper limits $X_{(i,D+)}^{MAX}$ and $X_{(i,D-)}^{MAX}$, and $a_1 > a_2$, $b_1 > b_2$.

Customer Optimization:

$$\max_{X_i^{D+}, X_i^{D-}} \mathrm{a}\log(\mathrm{X}+1) + \mathrm{b}\log(\mathrm{Y}+1) - P_{(D+)}X_i^{D+} - P_{(D-)}X_i^{D-} — P_0 \qquad (4\text{-}16)$$

$$\text{s.t. } X_i^{D+} \le X_{(i,D+)}^{MAX}, X_i^{D-} \le X_{(i,D-)}^{MAX} \qquad (4\text{-}17)$$

$$\text{a}\log(\text{X}+1)+\ \text{b}\log(\text{Y}+1)-P_{(D+)}X_i^{D+}-P_{(D-)}X_i^{D-}-P_0\geq 0$$

Provider Optimization:

$$\max_{P_0,P_{(D+)},P_{(D-)}} f(P_{(D+)}X_1^{D+}+P_{(D-)}X_1^{D-}+P_0)+g(P_{(D+)}X_2^{D+}+P_{(D-)}X_2^{D-} + P_0)-C \quad (4\text{-}18)$$

Where $(X_i^*, X_i^\#)$ = argmax $[U_i(X_i^{D+},\ X_i^{D-})-P_{(D+)}X_i^{D+}-P_{(D-)}X_i^{D-}-P_0]$ (4-9)

$$\text{s.t. } X_i^{D+}\leq X_{(i,D+)}^{MAX},\ X_i^{D-}\leq X_{(i,D-)}^{MAX} \quad (4\text{-}20)$$

$$U_i(X_i^{D+},\ X_i^{D-})-P_{(D+)}X_i^{D+}-P_{(D-)}X_i^{D-}-P_0\geq 0$$

$$\sum_i(P_{(D+)}X_i^*+P_{(D-)}X_i^\#+P_0)-C\geq 0$$

Proposition 3.

If provider adopts with pay-per-use, when d$X_{(i,D+)}^{MAX}$ > g, the optimal price $P_{(D+)}=\frac{a}{X_{(i,D+)}^{MAX}+1}$; when $fX_{(i,D-)}^{MAX}$ > g, $P_{(D-)}=\frac{b}{X_{(i,D-)}^{MAX}+1}$. And the optimal profit is:

$$d\left(\frac{a_1X_{(i,D+)}^{MAX}}{X_{(i,D+)}^{MAX}+1}+\frac{b_1X_{(i,D-)}^{MAX}}{X_{(i,D-)}^{MAX}+1}\right)+g(a_2-\frac{a_1}{X_{(i,D+)}^{MAX}+1}+b_2-\frac{b_2}{X_{(i,D-)}^{MAX}+1})-C$$

Otherwise, $P_{(D+)}=\frac{a_1}{X_{(i,D+)}^{MAX}+1}$ and $P_{(D-)}=\frac{b_2}{X_{(i,D-)}^{MAX}+1}$. Meanwhile, the maximum profit of provider is:

$$(d+g)\left(\frac{a_1X_{(i,D+)}^{MAX}}{X_{(i,D+)}^{MAX}+1}+\frac{b_1X_{(i,D-)}^{MAX}}{X_{(i,D-)}^{MAX}+1}\right)-C$$

Proposition 4.

If provider adopts with subscription, the optimal price is:

$a_2 \log\left(X_{(i,D+)}^{MAX} + 1\right) + b_2 \log X_{(i,D-)}^{MAX} + 1)$.

And the optimal profit is:

$$(d+g)\left(\frac{a_1 X_{(i,D+)}^{MAX}}{X_{(i,D+)}^{MAX} + 1} + \frac{b_1 X_{(i,D-)}^{MAX}}{X_{(i,D-)}^{MAX} + 1}\right) - C$$

II. High and Low-Demand Customers

Assuming that there are *d* high-demand customers (i = 1) and *g* low-demand customers (i = 2), it focuses on whether different level of demand impacts the provider's pricing strategy. Suppose the consumption upper limits of high-demand customers are $X_{(1,D+)}^{MAX}$ and $X_{(1,D-)}^{MAX}$, and the consumption upper limits of low-demand customers are $X_{(2,D+)}^{MAX}$ and $X_{(2,D-)}^{MAX}$. Obviously, $X_{(1,D+)}^{MAX} > X_{(2,D+)}^{MAX}$, $X_{(1,D-)}^{MAX} > X_{(2,D-)}^{MAX}$. Also, $a_1 = a_2 = a$, $b_1 = b_2 = b$.

Provider Optimization

$$\max_{P_0, P_{(D+)}, P_{(D-)}} \sum_i (P_{(D+)} X_i^* + P_{(D-)} X_i^{\#} + P_0) - C \qquad (4\text{-}21)$$

Where $(X_i^*, X_i^{\#})$ = argmax $[U_i(X_i^{D+}, X_i^{D-}) - P_{(D+)} X_i^{D+} - P_{(D-)} X_i^{D-} - P_0]$ (4-22)

$$\text{s.t. } X_i^{D+} \le X_{(i,D+)}^{MAX}, X_i^{D-} \le X_{(i,D-)}^{MAX} \qquad (4\text{-}23)$$

$$U_i(X_i^{D+}, X_i^{D-}) - P_{(D+)} X_i^{D+} - P_{(D-)} X_i^{D-} - P_0 \ge 0$$

$$\sum_i (P_{(D+)} X_i^* + P_{(D-)} X_i^{\#} + P_0) - C \ge 0$$

Proposition 5.

If provider adopts with pay-per-use, when g$X^{MAX}_{(2,D+)}$ > d, the optimal price when demand is high is $P_{(D+)} = \frac{a}{X^{MAX}_{(2,D+)}+1}$; when g$X^{MAX}_{(2,D-)}$ > d, the optimal price when demand is low is $P_{(D-)} = \frac{b}{X^{MAX}_{(2,D-)}+1}$. The maximum profit of provider is:

$$(d+g)\left(\frac{aX^{MAX}_{(2,D+)}}{X^{MAX}_{(2,D+)}+1}+\frac{bX^{MAX}_{(2,D-)}}{X^{MAX}_{(2,D-)}+1}\right)-C$$

Otherwise, $P_{(D+)} = \frac{a}{X^{MAX}_{(1,D+)}+1}$ and $P_{(D-)} = \frac{b}{X^{MAX}_{(1,D-)}+1}$. Meanwhile, the maximum profit of provider is:

$$d\left(\frac{aX^{MAX}_{(1,D+)}}{X^{MAX}_{(1,D+)}+1}+\frac{bX^{MAX}_{(1,D-)}}{X^{MAX}_{(1,D-)}+1}\right)+g(\frac{aX^{MAX}_{(2,D+)}}{X^{MAX}_{(1,D+)}+1}+\frac{bX^{MAX}_{(2,D-)}}{X^{MAX}_{(1,D-)}+1})-C$$

Proposition 6.

If provider adopts with subscription, the optimal price is:

$a\log\left(X^{MAX}_{(2,D+)}+1\right)+b\log X^{MAX}_{(2,D-)}+1)$.

And the optimal profit is:

$$(d+g)\left(a\log\left(X^{MAX}_{(2,D+)}+1\right)+b\log(X^{MAX}_{(2,D-)}+1)\right)-C$$

Corollary 1.

Subscription can help cloud service providers get more profit. In other words, subscription is a better pricing mechanism than pay-per-use.

4.2 Dynamic Auction Design for Both Developing and Maturing Stages

4.2.1 Problem Statement

The hybrid pricing mechanism is formalized below:

(1) There exist m sellers, M = $\{m_j$, j = 1, 2, …, m$\}$. The sellers (m_j, j = 1, 2, …, m) themselves are also the cloud providers, like Amazon, Google, Microsoft, IBM, etc. Each provider is represented by an agent.

(2) There exist n buyers, N= $\{n_i$, j = 1, 2, …, n$\}$. The customers (n_i, i = 1, 2, …, n) are also the bidders, who could be individuals, companies, or institutions, etc.

(3) Second price sealed-bid double auction design. In order to avoid cheating or any strategic maneuvering, a second price sealed-bid auction is adopted with. The winning bidder will pay the second highest price for the cloud services payment. Customers have more incentives to bid, due to less expenses they will pay.

(4) Individual Rationality (IR): All participants (provider and customer) are rational. In other words, each participant would seek some benefit through the procedure, otherwise, no participant wants to join the auction. For instance, customer i's bid should be greater than the marketing price (P), at least the two prices are equal: $B_i \geq P$. on the other side, the marketing price (P) should be greater than provider's estimation (B_j), to the most provider's bid equals to the marketing price: $P \geq B_j$. In practice, IR is a natural phenomenon that applicable to each unit in game theory. Each participant has the incentive to act in an auction design, because of the potential nonnegative gains through bidding auction procedure.

(5) Truthfulness (TF): Truthfulness is also known as incentive compatibility (IC) or strategy-proof [34, 35]. Based on Nash Equilibrium, each participant should report a truthful value (V) if he or she intend to optimize profits and utility. Otherwise, if some of the participants choose untruthfully bidding ($B_j \neq V_j$ or $B_i \neq V_i$), they will suffer potential losses. Truthfulness is critical in maintain a well-being environment in the cloud computing business: a trusted, fairness, and efficient market.

(6) Assume that within time T, all customers have submitted a total of s requests, e.g., Q = $\{Q_s$, s = 1, 2, …$\}$. Each request from a customer is consisted of five components.

$$Q_i = (Budget_i, Starttime_i, Runtime_i, Deadline_i, Bun\_Resource_i).$$

Such as, $Budget_i$ is the budget that is for Q_i, $Starttime_i$ is the submission time of Q_i, $Runtime_i$ is the running time of Q_i, $Deadline_i$ is the due time of Q_i.

(7) $Max\_Respond_i$ is the longest responding time of Q_i that a customer can tolerant.

$$Max\_Respond_i = Deadline_i - Starttime_i - Runtime_i$$

(8) The participant's goal is to bid the service for the minimal expenses before the deadline. The provider seeks to maximize resource revenue. Hence, the resource provider will raise the asking price if possible, and the customer will give a relatively lower bid.

4.2.2 Proposition and Conditions

Proposition 7.

An economically efficient auction design can get the same profits as a fixed pricing strategy.

Proposition 8.

A double auction pricing mechanism can generate more revenues than an economically efficient auction design.

Corollary 2.

A double auction pricing mechanism is more appropriate for provider or customer to employ than a fixed pricing strategy.

The detailed proof is in the following section and appendix.

4.3 The Bidding Procedure

In this section, the detailed bidding procedure and algorithms are illustrated and discussed. There are no unusual steps in the proposal auction design, only the first step is different from the classical mechanisms. For instance, the first step is reserved QoS-based pricing model, the second step is bids submission, the third step is bids matching, the fourth step is winner determination, the fifth step is marketing price calculation, the last step is transaction and payment. The detailed procedures are depicted in the following picture (Fig. 4-2).

4.3.1 Step I: Reserved QoS-based Pricing Model

This step estimates the relation between the QoS indicators and reserved price of cloud resources. The QoS indicators include availability (A_x), elasticity (E_x), reliability (R_x), security (S_x), etc. The reserved price of cloud service is P_R. The function is

$$P_R = F(X) = F(A_x, E_x, R_x, S_x, \dots) \tag{4-24}$$

Specifically, P_R is a reference to both provider and customer. Both parties send their bids based on the reserved price respectively. The customer i's bid is Bid_i^t, and the provider j's bid is Ask_j^t.

4.3.2 Step II: Bids Submission

Customers provide their bids and QoS preferences to the auctioneer, providers act the same process as well.

Customers' bids:

$$B_1^t, \dots, B_i^t, \dots \tag{4-25}$$

Providers' bids:

$$Ask_1^t, \dots, Ask_j^t, \dots \tag{4-26}$$

4.3.3 Step III: Pairing Bids

Providers have capability to fulfill different types of cloud services along with all QoS requirements as customers expected. Specifically,

$$X_j^t \geq X_i^t \tag{4-27}$$

4.3.4 Step IV: Winner Determination

Customers' bids are ordered decreasingly, while providers' bids are sorted increasingly. All participants are truthful bidders, aiming at the complete process is monotonic [241-246].

Lemma 1: If one customer can win with bidding of B_i^t, he or she will continue to win for any ($B_i^{t'} > B_i^t$) bid.

4.3.5 Step V: Marketing Price Calculation

Revenue-approximating scheme

In the auction, the price paid by the winning customer equals the second highest price. The pricing rule can attract more customers with budget constraint and avoid strategy maneuver [54-56].

Based on Equations 3-7 and 3-8, a winning customer *i*'s bidding price (Bid_i^t) is the second highest bids:

$$Bid_i^t = Bid_{i^-}^t = BidREV_{i^-} \times (1 + (\frac{Respond_{i^-}^t}{ResMax_j})^\beta) \tag{4-28}$$

Hence, a winning customer marketing price (P):

$$P = Bid_{i^-}^t \tag{4-29}$$

4.3.6 Step VI: Transaction

Based on SLA and the bidding procedure, an agreement between winning customer and provider will be executed. The customer pays the winning cloud resource by the second highest price, the provide provisions the winning resource through the Internet.

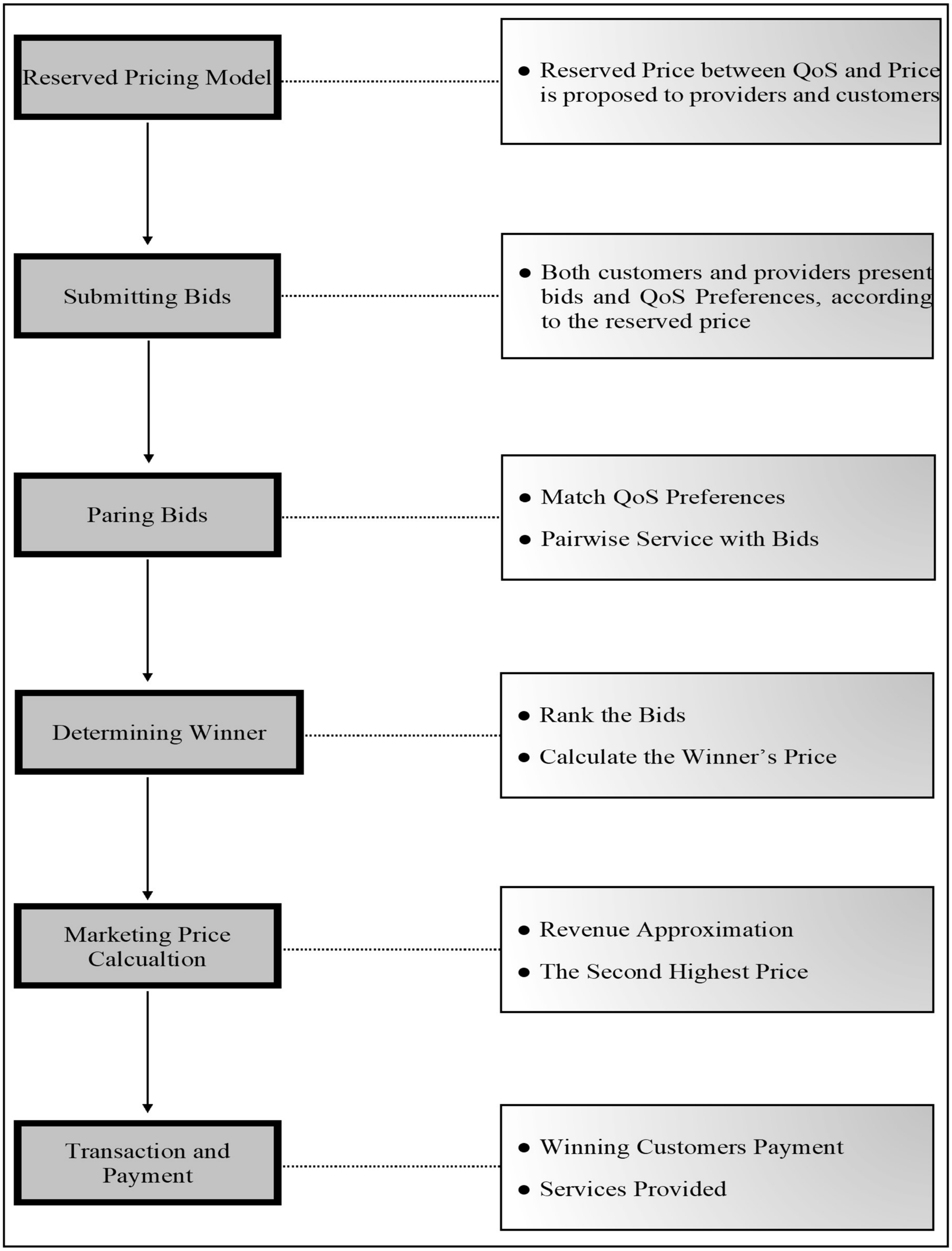

Fig. 4-2. The Detailed QoS-based Bidding Procedure

CHAPTER 5

LIMITATION AND FUTURE DIRECTION

This chapter is dedicated to discussing limitations and potential research directions.

5.1 The Issues of Current Cloud Pricing Mechanisms

Several other interests may attract future study. It would be attractive to establish a uniform and fully competitive auction mechanism [251, 252] to allocate resources to more customers, like individual, small companies, medium companies, and even big companies. Another important feature of cloud service is that we need to carefully consider the reusability. Cloud services can also be reused. Some users may complete the tasks before the bidding contract, and it is best to resell the resources they have [253. 254]. If there is no effective auction mechanism that the users can use, it will be difficult to resell the services because of the time issue. Future auction designs can illustrate reusability issues in the algorithms [255-257].

Providers will compete with each other and will submit bids related to a guaranteed QoS. The mathematical issue (NP-Hardness) and the computational complexity should be carefully considered, as well [258]. Another direction to consider is to adjust the QoS metrics. We employed only the availability as the indicator of QoS of this study. Multiple indicators, such as security, can be added to represent the exponential relationship between price and QoS. The more QoS metrics that are added into the auction algorithm, the more accurate and practical the estimates will be. There are malicious indicators representing cloud QoS [259, 260]. Thus, the algorithms embedded with QoS metrics are more complicated than normal mathematical models. A potential approach is to implement deep learning algorithms to estimate real values of cloud resources, according to the training layer (historical pricing records) and the output layers (estimation results) [261-264]

5.2 The Marketing Condition of Supply and Demand

In the thesis, the proposed hybrid pricing strategy works only for the marketing condition that demand is not greater than supply. This situation is very similar as cloud industry in practice. Cloud computing is still on the early stage, more and more institutions and companies are joining its development, and more and more users (companies or individuals) are becoming familiar with cloud-relevant resources. In the nearly future, cloud services will be more popular around the world. Hence, a complete marketing condition, including supply is less than demand, supply equals to demand, and supply is greater than demand, should be considered and discussed. According to different marketing condition, provider or customer can use distinguished pricing strategy to optimize profits as expected. Furthermore, beyond marketing conditions, there exist many dynamic mechanisms that can suit for pricing cloud computing, from technological perspective, revenue optimization perspective, or economic efficiency, etc. in other words, pricing strategy is always a critical factor impacting the development of cloud computing, the success of companies, and the benefits of end-users.

5.3 The Decentralized Cloud Trading Platform

In a cloud environment, application scalability benefits both providers and customers. Customers need on-demand and QoS-guaranteed cloud services. The dominant pricing strategies of leading companies that market the cloud is to use certain fixed pricing models to sell their cloud-related services. Auction design is a viable and an effective method for pricing cloud service. The decentralized P2P cloud trading platform is a good complement to the centralized cloud pricing mechanisms [265-268].

The blockchain and its relevant mechanisms are quickly emerging and are increasingly being applied in industries. As a decentralized system, the blockchain has been attracting more and more attention because of its popular features, such as decentralization, mutual trust, transparency, traceability and unforgeability, anonymity, credibility, etc. [269-272]. The integration of blockchain and cloud computing is a good example of a blockchain application. The blockchain has the potential to provide a decentralized trading network for peer-to-peer transactions. The participants are flexible enough to be able to prosecute transactions through a blockchain-based trading system [273, 274].

Depending on each customer's different QoS requirements for cloud services [68], [232], users need a viable and efficient pricing system that is adaptable to the allocation and optimization of the available cloud resources. The buyers will bid for their own QoS preferences for better service, and the sellers will select buyers based on their bids, provide resources for higher-priced buyers, and guarantee the cloud's QoS. Buyers can freely choose resources according to their own needs. However, due to the liquidity of marginal customers, whose bidding is uncertain, it may be difficult to estimate the demand based on the existing bids [222]. The decentralized P2P cloud trading platform has the potential to improve both economic efficiency and optimal profits. Also, the platform can set up a relatively free trading environment without unnecessary intervention and avoiding various costs [274, 275]. The characteristics of the seller and the buyer can be exchanged through the blockchain-based trading system

5.2.1 Adaptability of Blockchain in Cloud Computing

As a distributed shared ledger, the blockchain implements chained storage by implementing one-way connections of adjacent blocks by hash values. Each node of the blockchain has a complete copy of the ledger. It is convenient to view and to prove transaction data in real time. The openness and transparency of the distributed ledger records can effectively maintain data security and transaction smoothness. Using blockchain technology, the anonymity of the transaction and the no data caching function provide important guarantees for P2P transactions and for two-way interaction [265, 266]. The decentralized verification process is separated from any unnecessary centralized intervention, such as auctioneer, government agencies, and banking organizations. Its decentralized features are consistent with the non-central characteristics of distributed resources. Thus, the blockchain-based distributed cloud trading system can realize the immediate settlement of benefits, and the P2P direct transaction also greatly reduces the intermediate costs [275-277]. In this study, the blockchain platform is a hybrid decentralized system that consists of sellers, buyers, and necessary third parties, such as a supervision authority or a financial institution.

5.2.2 Theoretical Framework

The system has been designed into three layers (Fig. 5-1). The user layer is responsible for providing user services and cloud service management, such as user registration, user login, public and private key management, cloud service transaction information, and user right inquiry. On the hybrid blockchain platform, users consist of three groups of participants: the seller (provider), the buyer (customer), and third parties, such as a supervision authority or a financial institution. Any entity that intends to join the network needs to apply for that right, which will be assessed through certain standards for each of the three groups, respectively. Only authorized users can register and access the platform. In this way, nonqualified participants have no chance to be involved with the system. The hybrid platform keeps the trading procedure more secure and straightforward. The user layer also takes control of the public and private keys and the transaction information, in order to assist the involved participants to track the related records in a safe and transparent manner. In the hybrid decentralized trading system, the QoS Monitor is in charge of collecting, recording, and estimating the relationship of QoS availability and price, based on previous trading record.

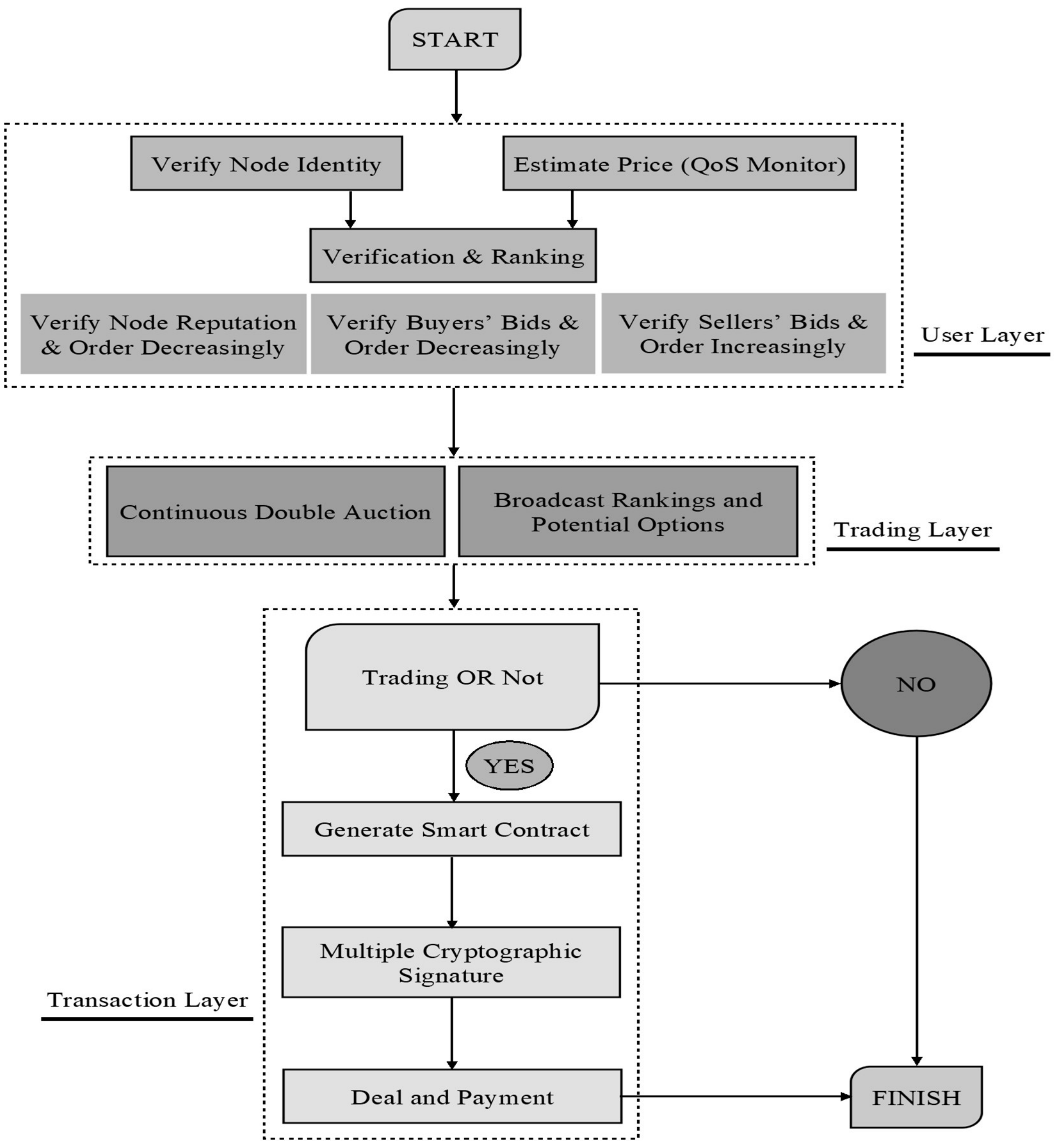

Fig. 5-1 Blockchain-based Decentralized Cloud Trading Platform

The trading layer implements the auctioning procedure. A continuous double auction design is embedded in the hybrid blockchain system, and it executes bidding, matching, and trading. A double auction offers both buyer and seller the opportunity to bid for cloud resources, such that a buyer can obtain a service at a lower price, while a seller can acquire better revenue. The continuity design provides users (the seller and the buyer) with more chances to trade cloud resources. For instance, for the first time, a deal might not occur, due to the disagreement between seller and buyer. Both the seller and the buyer can bid again for another cloud resource. Or, a previous buyer could change to be a seller, who intends to sell cloud resources via the proposed auction network, because cloud resources still exist after what the previous buyer had bought. The detailed auction processes will be addressed in the Section that discusses The Auction Procedure.

In the transaction layer, the blockchain will be generated. Consensus is the core issue of blockchain technology in a decentralized environment. The mechanism adopted is DPoS (Delegated Proof of Work) [278-280], which defines the stake as proof of the higher price associated with the QoS being guaranteed. Specifically, the system will assign the right of block ledger to the node that represents the potential winning price associated with the guaranteed QoS of cloud services. Under this circumstance, aiming at competing for the right to ledger, suppliers will seek to improve QoS or to cut costs of cloud service. To customers, they will obtain higher-performance or lower-price cloud services. The complete network can process in a virtuous eco-system. As an important program in the blockchain system, smart contracts include a series of transaction information, such as trading hours, amounts, buyers and sellers, and categories of cloud service. Smart contracts can update content in a timely manner, based on various factors in the decentralized trading market.

5.2.3 Peer-to-Peer Trading Mechanism

The blockchain is a decentralized technology that enables peer-to-peer transactions through cloud service providers, cloud users, authorities, and financial institutions as nodes that integrate and constitute the blockchain network. The blockchain guarantees transaction security, transparency, and data reliability through digital signatures, consensus mechanisms, smart contracts, and asymmetric encryption algorithms [273-276]. Blockchain technology ensures that any node can implement interconnection and P2P transactions.

The blockchain-based cloud trading platform estimates the current trading duration, based on previous trading time. The blockchain platform confirms the reputation value of each node and ranks the values in descending order. The system collects the buyers' bids and relevant information and arranges them in descending order, whereas the system collects the sellers' prices and the relevant information and arranges them in ascending order. According to the reputation value, each node of the buyer/seller will be given a matching range of reputation. The platform broadcasts a sorted list, and each node can match the range. The node decides whether to conduct the transaction: 1) The node confirms the transaction, and the system reviews the transaction. If the transaction is verified, a smart contract is generated. The buyer and the seller ultimately confirm the execution of the contract through multiple signatures and credit the reputation after the transaction is completed. If the verification fails, it is determined that the transaction was unsuccessful, and the node enters the next round of auctioning. 2) The node is inconsistent with the transaction, and the system again prompts the node to determine whether to adjust the bid or the transaction volume. If the node adjusts the bid or the volume, the previous transaction step is repeated until the transaction is completed; if the node does not adjust the bid or volume, the transaction is terminated directly.

5.2.4 Calculate Node Reputation Values and Matching Ranges

The value of node reputation is R_k^r. Each node can select a trading party as the selectable range μ_k^r. If a node has not completed a match before the expiration time of a transaction period, the system may determine that the node is inactive during the current time period and will use the appropriate reputation value as the penalty deduction. Through the list of reputation values, the system can not only reward reputable nodes, but also can encourage market integrity transactions, and can cancel the recording rights of inactive nodes or malicious nodes to correctly operate the decentralized trading platform [281]. $R_k^r = [R_1^r, R_2^r, \dots R_k^r]$ and $\mu_k^r = [\mu_1^r, \mu_2^r, \dots \mu_k^r]$. The function of R_k^r is

$$R_k^r = \frac{1}{2} * \left(\sum_{i=1}^{r} \frac{\delta_k^r}{\theta_k^r} + \sum_{i=1}^{r} \frac{\theta_k^r}{t_k^r} \right), R_k^r \in (0,1) \qquad \text{5-1}$$

δ_k^r is the number of node k's the good reputation, θ_k^r is the number of node k's real transaction, and t_k^r is the number of node k's bidding. R_k^r is determined by the percentage of good reputation and the percentage of participating active. The function of μ_k^r is

$$\mu_k^r = N_k^r * (1 - R_k^r) \qquad \text{5-2}$$

N_k^r represents the number of nodes that finish transaction in a trading cycle. Table V is the matching range for the six nodes, according to Table 5-1.

TABLE 5-1

Matching Range Based on Node Reputation Value

Customer	Reputation Rank	Selectable Providers	Provider	Reputation Rank	Selectable Customers

B_i^2	Top 10%	$B_j^2, B_j^3 B_j^1$	B_j^2	Top 60%	B_i^2, B_i^1, B_i^3
B_i^1	Top 60%	B_j^2, B_j^3	B_j^3	Top 30%	B_i^1, B_i^3
B_i^3	Top 30%	B_j^2	B_j^1	Top 10%	B_i^2

5.2.5 Comparison between Traditional and Decentralized Trading Systems

Traditional cloud transactions rely on third-party institutions such as banks, with many transaction processes that lead to low efficiency and long durations. All of the data, such as user account information and transaction history, is stored and regulated in the centralized organization's database. The security and privacy are poor; once the database is attacked, the data is difficult to recover. Users only have their own records and cannot know the transaction records of other users; thus, the establishment of the mutual trust market is affected [282], [283].

In a blockchain-based decentralized cloud trading system, each node becomes an independent seller or buyer, and each entity is evenly dispersed. The form of direct P2P cloud trading has the potential to reduce unnecessary costs, such as power loss and transaction costs. It is also possible to conduct cloud transactions between nodes in different regions and to allocate cloud P2P transactions across regions [284, 285]. All of the transactional information and nodes can be anonymous, to ensure users' privacy and security. The decentralized platform eliminates the need for a central auctioneer, improves data sharing and security, optimizes revenues and efficiency, and increases mutual trust between market entities [286, 287]. The following table (Table 5-2) briefly addresses the differences between the centralized and the decentralized cloud trading platforms.

TABLE 5-2

Differences between Centralized and Decentralized Trading Platform

Feature	Centralized	Decentralized
Trading Mode	Centralized (Auctioneer)	Decentralized (No Intervention)
Resource Consuming	High	Low
Transaction Cost	High	Low
Data Storage	Central Database	Decentralized Ledger
Data Security	Low	High
Data Privacy	Low	High
Information Transparency	Low	High
Flexibility	Supervised	Freedom

In a cloud environment, the dominant pricing strategies of leading companies that market the cloud is to use certain fixed pricing models to sell their cloud-related services. Auction design is a viable and an effective method for pricing cloud service. The decentralized P2P cloud trading platform is a good complement to the centralized cloud pricing mechanisms [288, 289].

5.4 The Impact of QoS-based Pricing Strategy on Customer Purchasing Behavior

Another direction is an empirical study that adopts with the Unified Theory of Acceptance and Use of Technology (UTAUT) to study acceptance and use of cloud service in a consumer context [290-292]. Our model conducted seven constructs into UTAUT: performance expectancy, effort expectancy, social influence, facilitating condition, price value, QoS expectation, network externalities, and practical risks. Individual perspectives, such as age, gender, and experience, have moderating effects on behavioral intention and cloud service use. The researched model is depicted in the following (Fig. 5-2).

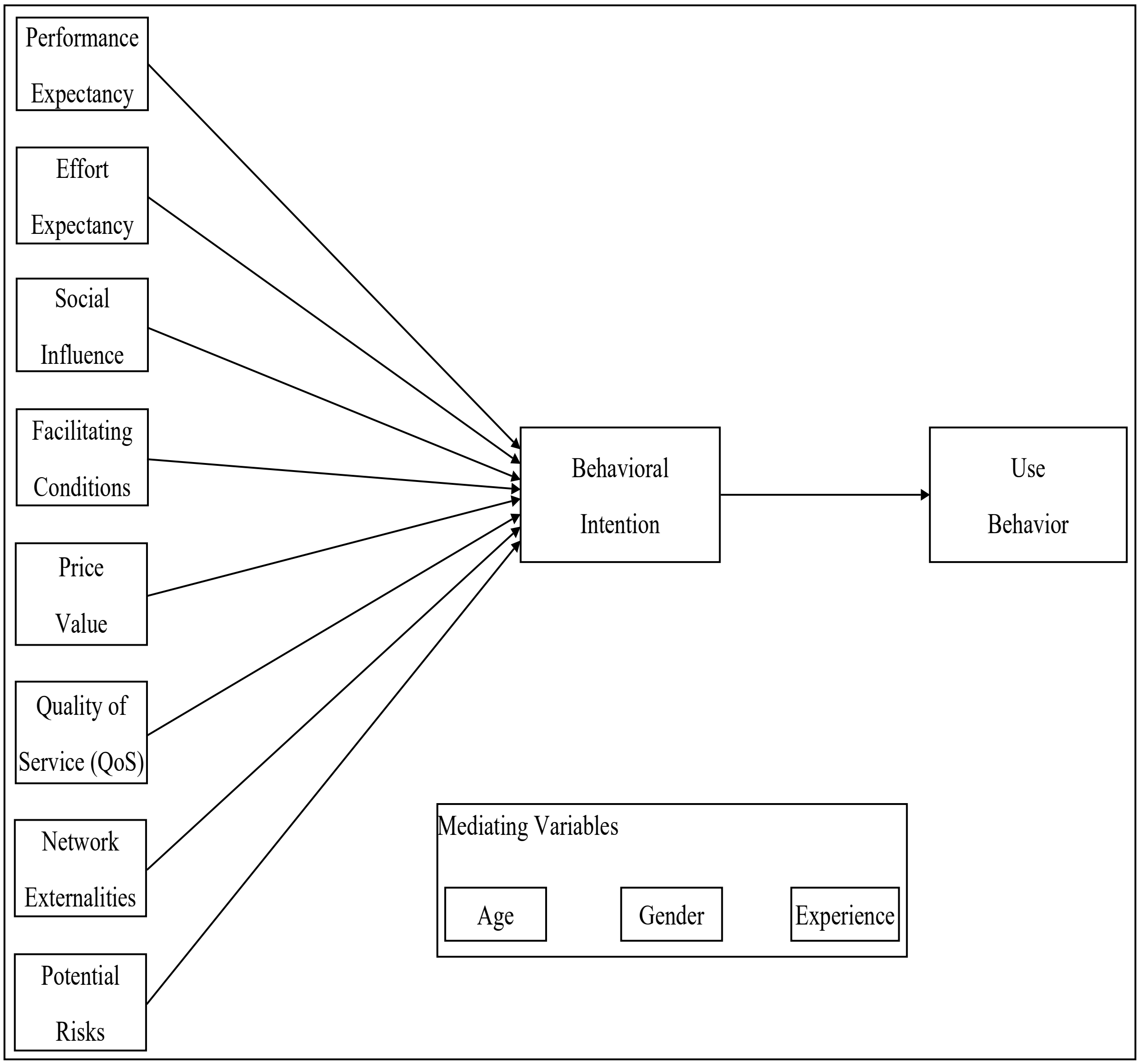

Fig. 5-2 The Research Model of Cloud-based UTAUT

Based on the model, two research questions will be investigated:

1. What factors influence consumer’s purchasing behavior of cloud service?

The first four variables of UTAUT, performance expectancy, effort expectancy, social influence, facilitating condition, have systematically investigated and explained in the extant study [290], [293, 294], the other four factors, price value, QoS expectation, network externalities, and practical risks, have not yet indicated very well. This study will focus on the last four variables. For instance, for price value, consumers are price sensitive whether they have budget constraint or not, they would seek to save expenses but obtain the same level of cloud resources. QoS (Quality of Service) is a critical indicator to estimate cloud resource value and to attract potential consumers [23]. There is no such study in IS to illustrate this phenomenon. Cloud computing has the potential to benefit consumers much more, if more consumers join the cloud systems. From a company or provider, how to conduct cloud computing platform to perform the network externalities of cloud computing is an interesting thinking in practice. Furthermore, more and more consumers accept and use cloud services, there exist potential risks when using. How to effectively control or avoid potential risks will be always a hot topic towards cloud computing implementation and cloud industry.

2. What different consumer purchasing behaviors between China and US?

For the second research question, there will be a comparison between consumers from US and China, we will collaborate two popular cultural research frameworks together to explore the study: Hofstede Cultural Framework [295, 296] and Schwartz Polar Dimension [297-300]. Among these, Hofstede Cultural Framework is the mostly used guidance to analyze cultural differences between two cultures; Schwartz Polar Dimension will be employed as well, especially some of important factors that don’t discussed in Hofstede Cultural Framework.

The empirical results were from two portions of survey, with the same questionnaires data collected from Chinese and American individual consumers. In total, 5000 consumer data are validated and support our hypotheses. There exist several different purchasing behaviors toward cloud services between consumers from China and US.

The goals and contribution of the empirical study are:

(1) To summarize and explain the extant UTAUT relevant models:

(2) To construct determinants that impact consumer purchasing behavior toward cloud services:

(3) To empirically validate the derived UTAUT: An empirical test of

We conducted an extensive survey of individual consumers from both China and US to figure out what factors impacting their decision on purchasing cloud services based on the proposed UTAUT model. this survey provides important benchmarking information for individual customers and cloud providers seeking to understand how cloud relevant companies compose their pricing strategies and how to improve the comprehensive cloud resources quality to attract more potential customers and make more revenues.

CHAPTER 6

CONCLUSION

This chapter is dedicated to concluding the study.

The pricing mechanism is one of the core elements of a business model. A good pricing mechanism is a key factor for the success of cloud industry. The research of cloud pricing has far-reaching significance for the development of cloud computing. It is of great theoretical and practical significance for cloud service providers to formulate reasonable pricing strategies in order to attract more potential customers and obtain more profits. Once applied appropriately, the pricing mechanisms can change consumer purchasing behavior and determine the competitive position of cloud service providers in the market. This article synthesizes the research on pricing strategies related to cloud computing services and proposed a hybrid QoS-based cloud pricing mechanism. Based upon the pricing theory and game theory, the hybrid pricing mechanism is more beneficial to cloud service providers and customers.

The proposed hybrid QoS-based pricing mechanism has the following advantages. (1) Solving Problems of Fixed Pricing Strategy. The price of a resource cannot be dynamically modified based on resource usage between supply and demand. Cloud providers will suffer potential revenue loss due to more potential customers will be involved and price will be fluctuated. The QoS level and performance of the cloud services obtained is directly related to the expenses a customer needs to pay. If the same amount of cloud services is used, the higher the performance or the higher QoS level of cloud services a customer requires, the higher prices of the related cloud services will be. (2) The QoS-based pricing model can present a clear reserved price to both providers and customers. Differentiated QoS threshold represents different prices to cloud services; the price itself reflects the user's preference for QoS. Overall, the hybrid pricing mechanism can explore both the two pricing strategies' advantages and to provide supplier and customer expected benefits. (3) Attractive to customers. Based on budget constraints, customers could customize cloud services as they expect. Customers have good opportunity to price/bid the expected cloud services.

This study potentially plays important roles in academia and practice. This is the first paper combine QoS metrics (technological perspective of cloud computing) and dynamic pricing mechanisms (subscription and auction design) together. It is potential to offer certain insights and guidance for researchers who are interested in pricing cloud computing. For instance, many different types of auction can be designed and explored, especially double and combinatorial auction designs. QoS metrics are good variables to estimate values of cloud computing, and cloud computing includes other technological factors impacting the overall performance and price. A hybrid QoS-based pricing mechanism is built to effectively distribute available cloud resources based on marketing conditions, such as when supply > demand, pricing strategy is different based on marketing price. The pricing strategy adopted with should benefit to providers or customers, aiming at achieving better outcomes. The model presents an appropriate reserved price of cloud resources, which will be as reference to both providers and customers. Throughout the complete pricing process, a provider could easily locate its own pricing strategies and the status of its cloud computing development; a customer could easily seek available cloud services based on its own QoS expectations and budget constraints.

REFERENCES

[1] S. Marston, Z. Li, S. Bandyopadhyay, J. Zhang, and A. Ghalsasi, “Cloud computing—The business perspective,” *Decision support systems*, vol. 51, no. 1, pp. 176-189, 2011.

[2] W. Venters and E. A. Whitley, “A critical review of cloud computing: researching desires and realities,” *Journal of Information Technology*, vol. 27, no. 3, pp. 179-197, 2012.

[3] P. F. Hsu, S. Ray, and Y. Y. Li-Hsieh, “Examining cloud computing adoption intention, pricing mechanism, and deployment model,” *International Journal of Information Management*, vol. 34, no. 4, pp. 474-488, 2014.

[4] C. S. Yeoa, S. Venugopalb, X. Chua, and R. Buyyaa, “Autonomic metered pricing for a utility computing service,” *Future Generation Computer Syst.*, vol. 26, no. 8, pp. 1368-1380, 2010.

[5] R. Buyya, C. S. Yeo, S. Venugopal, J. Broberg, and I. Brandic, “Cloud computing and emerging IT platforms: vision, hype, and reality for delivering computing as the 5th utility,” *Future Generation computer systems*, vol. 25, no. 6, pp. 599-616, 2009.

[6] D. Paul, W. D. Zhong, and S. K. Bose, “Energy efficient cloud service pricing: a two-timescale optimization approach,” *Journal of Network and Computer Applications*, vol. 64, pp. 98-112, 2016.

[7] T. E. S. M. Ali and H. H. Ammar, “Pricing models for cloud computing services, a survey,” *Int. J. Comput. Appl. Technol. Res.*, vol. 5, no. 3, pp. 126-131, 2016.

[8] A. N. Toosi, K. Vanmechelen, F. Khodadadi, abd R. Buyya. “An auction mechanism for cloud spot markets,” *ACM Trans. Auton. Adapt. Syst.*, vol. 11, no. 1, pp. 2, 2016.

[9] D. Kumar, G. Baranwal, Z. Raza, and D. P. Vidyarthi, “A survey on spot pricing in cloud computing,” *Journal of Network and Systems Management*, vol. 26, no. 4, pp. 809-856, 2018.

[10] J. Li, Y. Zhu, J. Yu, C. Long, G. Xue, and S. Qian, “Online auction for IaaS clouds: towards elastic user demands and weighted heterogeneous VMs,” *IEEE Transactions on Parallel and Distributed Systems*, vol. 29, no. 9, pp. 2075-2089, 2018.

[11] S. Chen, H. L. Lee, and K. Moinzadeh, “Pricing schemes in cloud computing: utilization-based versus reservation-based,” *Production and Operations Management*, 2018.

[12] B. Yang, Z. Li, S. Jiang, and K. Li, “Envy-free auction mechanism for VM pricing and allocation in clouds,” *Future Generation Computer Systems*, vol. 86, pp. 680-693, 2018.

[13] B. Mikavica and A. Kostić-Ljubisavljević, “Pricing and bidding strategies for cloud spot block instances,” In 2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), *IEEE*, pp. 0384-0389, 2018.

[14] M. Al-Roomi, S. Al-Ebrahim, S. Buqrais, and I. Ahmad. “Cloud computing pricing models: a survey,” *International Journal of Grid and Distributed Computing*, vol. 6, no. 5, pp. 93-106, 2013.

[15] Z. Li, H. Zhang, L. O’Brien, S. Jiang, Y. Zhou, M. Kihl, and R. Ranjan, “Spot pricing in the cloud ecosystem: a comparative investigation,” *Journal of Systems and Software*, vol. 114, pp. 1-19, 2016.

[16] S. A. Tafsiri and S. Yousefi, “Combinatorial double auction-based resource allocation mechanism in cloud computing market,” *Journal of Systems and Software*, vol. 137, pp. 322-334, 2018.

[17] Z. Zhang, Z. Li, and C. Wu, “Optimal posted prices for online cloud resource allocation,” *Proceedings of the ACM on Measurement and Analysis of Computing Systems*, vol. 1, no. 1, pp. 1-26, 2017.

[18] P. Mitropoulou, E. Filiopoulou, M. Nikolaidou, and C. Michalakelis, “Pricing IaaS: a hedonic price index approach,” In International Conference on the Economics of Grids, Clouds, Systems, and Services, Springer, Cham, pp. 18-28, 2017.

[19] I. Bardhan, H. Demirkan, P.K. Kannan, R. J. Kauffman;R. Sougstad, “An interdisciplinary perspective on it services management and service science,” *Journal of Management Information Systems*, vol. 26, no. 4, pp. 13-64, 2010.

[20] B. Martens and F. Teuteberg, “Decision-making in cloud computing environments: a cost and risk-based approach,” *Information Systems Frontiers*, vol. 14, no. 4, pp. 871-893, 2012.

[21] T. Oliveira, R. Martins, S. Sarker, M. Thomas, and A. Popovič, “Understanding SaaS adoption: the moderating impact of the environment context,” *International Journal of Information Management*, vol. 49, pp. 1-12, 2019.

[22] N. Wang, H. Liang, Y. Jia, S. Ge, Y. Xue, and Z. Wang, “Cloud computing research in the IS discipline: a citation/co-citation analysis,” *Decision Support Systems*, vol. 86, pp. 35-47, 2016.

[23] S. W. Chou and C. H. Chiang, “Understanding the formation of software-as-a-service (SaaS) satisfaction from the perspective of service quality,” *Decision Support Systems*, vol. 56, pp. 148-155, 2013.

[24] S. Fremdt, R. Beck, and S. Weber, “Does cloud computing matter? an analysis of the cloud model software-as-a-service and its impact on operational agility,” In 2013 46th Hawaii International Conference on System Sciences, *IEEE*, pp. 1025-1034, 2013.

[25] H. B. Yang and M. A. Tate, “A descriptive literature review and classification of cloud computing research,” *Communications of AIS*, vol. 31, no. 2, pp. 35-60, 2012.

[26] S. H. H. Madni, M. S. A. Latiff, and Y. Coulibaly, “Resource scheduling for infrastructure as a service (IaaS) in cloud computing: challenges and opportunities,” *Journal of Network and Computer Applications*, vol. 68, pp. 173-200, 2016.

[27] S. Yuan, S. Das, R. Ramesh, and C. Qiao, “Service agreement trifecta: backup resources, price and penalty in the availability-aware cloud,” *Information Systems Research*, vol. 29, no. 4, pp. 947-964, 2018.

[28] P. Y. Chen and S. Y. Wu, “The impact and implications of on-demand services on market structure,” *Information Systems Research*, vol. 24, no. 3, pp. 750-767, 2013.

[29] A. K. Kar and A. Rakshit, “Pricing of cloud IaaS based on feature prioritization-a value-based approach,” In Recent Advances in Intelligent Informatics, Springer, Cham, pp. 321-330, 2014.

[30] E. Weintraub and Y. Cohen, “Optimizing cloud computing costs of services for consumers,” In Encyclopedia of Information Science and Technology, Fourth Edition IGI Global, pp. 1627-1637, 2018.

[31] S. Y. Wu and R. D. Banker, “Best pricing strategy for information services,” *Journal of the Association for Information Systems*, vol. 11, no. 6, pp. 339-366, 2010.

[32] S. H. Chun, “Cloud services and pricing strategies for sustainable business models: analytical and numerical approaches,” *Sustainability*, vol. 12, no. 1, pp. 49, 2020.

[33] C. Liu, Y. Au, and E. Ayaburi, “Pricing and Upgrade Strategies for Software Vendors in the Software-as-a-Service Market,” Thirty Sixth International Conference on Information Systems, Fort Worth, US, 2015.

[34] Q. Zhang, L. Cheng, and R. Boutaba, “Cloud computing: state-of-the-art and research challenges,” *Journal of internet services and applications*, vol. 1, no. 1, pp. 7-18, 2010.

[35] S. Y. Jing, S. Ali, K. She, and Y. Zhong, “State-of-the-art research study for green cloud computing,” *The Journal of Supercomputing*, vol. 65, no. 1, pp. 445-468, 2013.

[36] C. Wu, A. N. Toosi, R. Buyya, and K. Ramamohanarao, “Hedonic pricing of cloud computing services,” *IEEE Transactions on Cloud Computing*, early access, 2018.

[37] C. Wu, R. Buyya, and K. Ramamohanarao, “Cloud pricing models: Taxonomy, survey, and interdisciplinary challenges,” *ACM Computing Surveys (CSUR)*, vol. 52, no. 6, pp. 1-36, 2019.

[38] C. Wu, R. Buyya, and K. Ramamohanarao, “Value-based cloud price modeling for segmented business to business market,” *Future Generation Computer Systems*, vol. 101, pp. 502-523, 2019.

[39] A. Mohammadi and M. H. Rezvani, “A novel optimized approach for resource reservation in cloud computing using producer–consumer theory of microeconomics,” *The Journal of Supercomputing*, vol. 75, no. 11, pp. 7391-7425, 2019.

[40] W. Joe, “Cloudonomics: The Business Value of Cloud Computing,” JohnWiley & Sons, Hoboken, NJ, pp. 160, 2012.

[41] J. Weinman, “The cloud and the economics of the user and customer experience,” *IEEE Cloud Computing*, vol. 2, no. 6, pp. 74-78, 2015.

[42] J. Weinman, “The nuances of cloud economics,” *IEEE Cloud Computing*, vol. 1, no. 4, pp. 88-92, 2014.

[43] M. Parlińska and I. Petrovska, “Cloud computing and its benefits,” *Information Systems in Management*, vol. 6, 2017.

[44] B. Rajkumar, B. James, and M. G. Andrzej, “Cloud computing: principles and paradigms,” Wiley, Hoboken, NJ, pp. 3–37, 2011.

[45] Y. Feng, W. Zhijian, X. Feng, Z. Yuanchao, Z. Fachao, and Y. Shaosong, “A novel cloud load balancing mechanism in premise of ensuring QoS,” *Intelligent automation & soft computing*, vol. 19, no. 2, pp. 151-163, 2013.

[46] Y. Feng, W. Zhijian, and H. Qian, “A novel QoS-aware mechanism for provisioning of virtual machine resource in cloud,” *Journal of Algorithms & Computational Technology*, vol. 10. No. 3, pp. 169-175, 2016.

[47] H. Yu, S. Patnaik, S. Ji, L. Jia, and T. Yang, “Design and implementation of multi-agent online auction systems in cloud computing,” *International Journal of Enterprise Information Systems (IJEIS)*, vol. 13, no. 1, pp. 50-66, 2017.

[48] P. Mell and T. Grance, “The NIST definition of cloud computing.” NIST Special Publication, vol. 53, no. 6, pp. 50, 2011.

[49] S. Li, L. Xu, X. Wang, and J. Wang, “Integration of Hybrid Wireless Networks in Cloud Services Oriented Enterprise Information Systems,” *Enterprise Information Systems*, vol. 6, no. 2, pp. 165-187, 2012.

[50] F. Tao, Y. Cheng, L. D. Xu, L. Zhang, and B. H. Li, “CCIoT-CMfg: cloud computing and internet of things-based cloud manufacturing service system,” *IEEE Transactions on Industrial Informatics*, vol. 10, no. 2, pp. 1435-1442, 2014.

[51] D. VanderMeer, K. Dutta, and A. Datta, “A cost-based database request distribution technique for online e-commerce applications,” *MIS Quarterly*, vol. 36, no. 2, pp. 479-507, 2012.

[52] F. Budiono, S. Lau, and W. Tibben, “Cloud computing adoption for e-commerce in developing countries: contributing factors and its implication for Indonesia,” In PACIS, pp. 90, 2018.

[53] L. Jiang, L. D. Xu, H. Cai, Z. Jiang, F. Bu, and B. Xu, “An IoT-oriented data storage framework in cloud computing platform,” *IEEE Transactions on Industrial Informatics*, vol. 10, no. 2, pp. 1443-1451, 2014.

[54] H. Zhang, H. Jiang, B. Li, F. Liu, A. V. Vasilakos, and J. Liu, "A framework for truthful online auctions in cloud computing with heterogeneous user demands," *IEEE Transactions on Computers*, vol. 65, no. 3, pp. 805-818, 2016.

[55] L. Zhang, Z. Li, and C. Wu, "Dynamic resource provisioning in cloud computing: A randomized auction approach," In IEEE INFOCOM 2014-IEEE Conference on Computer Communications, *IEEE*, pp. 433-441, 2014.

[56] A. Beloglazov, J. Abawajy, and R. Buyya, "Energy-aware resource allocation heuristics for efficient management of data centers for cloud computing*," Future generation computer systems*, vol. 28, no. 5, pp. 755-768, 2012.

[57] K. Yang and X. Jia, "An efficient and secure dynamic auditing protocol for data storage in cloud computing," *IEEE transactions on parallel and distributed systems*, vol. 24, no. 9, pp. 1717-1726, 2012.

[58] A. Lin and N. C. Chen, "Cloud computing as an innovation: Perception, attitude, and adoption," *International Journal of Information Management*, vol. 32, no. 6, pp. 533-540, 2012.

[59] B. Xu, L. Xu, H. Cai, L. Jiang, Y. Luo and Y. Gu, "The design of an m-health monitoring system based on a cloud computing platform," *Enterprise Information Systems*, vol. 11, no. 1, pp. 17-36, 2017.

[60] G. Xu, M. Li, L. Luo, C. H. Chen, and G. Q. Huang, "Cloud-based fleet management for prefabrication transportation," *Enterprise Information Systems*, vol. 13, no. 1, pp. 87-106, 2019.

[61] T. Xia, W. Zhang, W. S. Chiu, and C. Jing, “Using cloud computing integrated architecture to improve delivery committed rate in smart manufacturing” *Enterprise Information Systems*, published online, 2020.

[62] M. Li, P. Lin, G. Xu, and G. Q. Huang, “Cloud-based ubiquitous object sharing platform for heterogeneous logistics system integration,” *Advanced Engineering Informatics*, vol. 38, pp. 343-356, 2018.

[63] N. Fernando, S. W. Loke, and W. Rahayu, “Mobile cloud computing: a survey,” *Future generation computer systems*, vol. 29, no. 1, pp. 84-106, 2013.

[64] Z. H. Zhan, X. F. Liu, Y. J. Gong, J. Zhang, H. S. H. Chung, and Y. Li, “Cloud computing resource scheduling and a survey of its evolutionary approaches,” *ACM Computing Surveys (CSUR)*, vol. 47, no. 4, pp. 1-33, 2015.

[65] C. N. Höfer and G. Karagiannis, “Cloud computing services: taxonomy and comparison,” *Journal of Internet Services and Applications*, vol. 2, no. 2, pp. 81-94, 2011.

[66] P. T. Endo, de Almeida Palhares, A. V., Pereira, N. N., Goncalves, G. E., Sadok, D., Kelner, J., ... and J. E. Mangs, “Resource allocation for distributed cloud: concepts and research challenges,” *IEEE network*, vol. 25, no. 4, pp. 42-46, 2011.

[67] A. Abdelmaboud, D. N. Jawawi, I. Ghani, A. Elsafi, and B. Kitchenham, “Quality of service approaches in cloud computing: a systematic mapping study,” *Journal of Systems and Software*, vol. 101, pp. 159-179, 2015.

[68] M. Armbrust, A. Fox, R. Griffith, A. D. Joseph, R. Katz, A. knowinski, G. Lee, D. Patterson, A. Rabkin, I. Stoia, and M. Zaharia. “A view of cloud computing,” *Communications of the ACM*, vol. 53, no.4, pp. 50-58, 2010.

[69] W. Shi, L. Zhang, C. Wu, Z. Li, and F. C. Lau, “An online auction framework for dynamic resource provisioning in cloud computing,” *ACM SIGMETRICS Performance Evaluation Review*, vol. 42, no. 1, pp. 71-83, 2014.

[70] L. Mashayekhy, M. M. Nejad, D. Grosu, and A. V. Vasilakos, “An online mechanism for resource allocation and pricing in clouds,” *IEEE transactions on computers*, vol. 65, no. 4, pp. 1172-1184, 2015.

[71] S. Nayak and A. Yassir, “Cloud computing as an emerging paradigm,” *International Journal of Computer Science and Network Security*, vol. 12, no. 1, pp. 61-65, 2012.

[72] B. Iyer and J. C. Henderson, “Preparing for the future: understanding the seven capabilities of cloud computing,” *MIS Quarterly Executive*, vol. 9, no. 2, pp. 117-131, 2010.

[73] B. Iyer and J. C. Henderson, “Business value from clouds: learning from users,” *MIS Quarterly Executive*, vol. 11, no. 1, pp. 51-60, 2012.

[74] N. Kyriakou and E. Loukis, “Cloud computing business value and human determinants: an empirical investigation,” In Proceedings of the 21st Pan-Hellenic Conference on Informatics, pp. 1-6, 2017.

[75] N. Sultan, “Knowledge management in the age of cloud computing and Web 2.0: Experiencing the power of disruptive innovations,” *International journal of information management*, vol. 33, no. 1, pp. 160-165, 2013.

[76] H. Rezaei, B. Karimi, and S. J. Hosseini, "Effect of cloud computing systems in terms of service quality of knowledge management systems," *Lecture Notes on Software Engineering*, vol. 4, no. 1, pp. 73, 2016.

[77] W. L. Shiau, "An evolution, present, and future changes of cloud computing services," *Journal of Electronic Science and Technology*, vol. 13, no. 1, pp. 54-59, 2015.

[78] P. Bonacquisto, G. Di Modica, G. Petralia, and O. Tomarchio, "A procurement auction market to trade residual cloud computing capacity," *IEEE Trans. Cloud Comput.*, vol. 3, no. 3, pp. 345–357, 2015.

[79] P. Mitropoulou, E. Filiopoulou, C. Michalakelis, and M. Nikolaidou, "Pricing cloud IaaS services based on a hedonic price index," *Computing*, vol. 98, no. 11, pp. 1075-1089, 2016.

[80] V. Cardellini, V. Di Valerio, and F. L. Presti, "Game-theoretic resource pricing and provisioning strategies in cloud systems," *IEEE Transactions on Services Computing*, 2016.

[81] G. Baranwal, D. Kumar, Z. Raza, and D. P. Vidyarthi, "Auction based resource provisioning in cloud computing," Springer, 2018.

[82] J. Han, X. Wu, and J. G. Liu, "An online sequential procurement mechanism under uncertain demands in multi-cloud environment," *International Journal of Approximate Reasoning*, vol. 103, pp. 152-167, 2018.

[83] Z. Zhu, J. Peng, K. Liu, and X. Zhang, "A game-based resource pricing and allocation mechanism for profit maximization in cloud computing," *Soft Computing*, vol. 24, no. 6, pp. 4191-4203, 2020.

[84] L. Deng, F. Xu, Y. Ren, S. Bao, H. He, and C. Li, "Resource allocation method based on combinatorial double auction mechanism in cloud computing," In 2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA), *IEEE*, pp. 801-806, 2018.

[85] N. C. Luong, P. Wang, D. Niyato, Y. Wen, and Z. Han. "Resource management in cloud networking using economic analysis and pricing models: a survey," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 954-1001, 2017.

[86] F. Sheikholeslami and N. Jafari Navimipour, "Auction‐based resource allocation mechanisms in the cloud environments: a review of the literature and reflection on future challenges," *Concurrency and Computation: Practice and Experience*, vol. 30, no. 16, e4456, 2018.

[87] S. Das, A. Y. Du, R. Gopal, and R. Ramesh, "Risk management and optimal pricing in online storage grids," *Information Systems Research*, vol. 22, no. 4, pp. 756-773, 2011.

[88] H. K. Cheng, Z. Li, and A. Naranjo, "Research note—cloud computing spot pricing dynamics: latency and limits to arbitrage," *Information Systems Research*, vol. 27, no. 1, pp. 145-165, 2016.

[89] V. Choudhary, "Comparison of software quality under perpetual licensing and software as a service," *Journal of management information systems*, vol. 24, no. 2, pp. 141-165, 2007.

[90] A. Benlian and T. Hess, "Opportunities and risks of software-as-a-service: Findings from a survey of IT executives," *Decision Support Systems*, vol. 52, no. 1, pp. 232-246. 2011.

[91] A. Benlian, M. Koufaris, and T. Hess, “Service quality in software-as-a-service: developing the SaaS-Qual measure and examining its role in usage continuance,” *Journal of management information systems*, vol. 28, no. 3, pp. 85-126, 2011.

[92] T. J. Winkler and C. V. Brown, “Horizontal allocation of decision rights for on-premise applications and software-as-a-service,” *Journal of Management Information Systems*, vol. 30, no. 3, pp. 13-48, 2013.

[93] D. Postmus, J. Wijngaard, and H. Wortmann, “An economic model to compare the profitability of pay-per-use and fixed-fee licensing,” *Information and Software Technology*, vol. 51, no. 3, pp. 581-588, 2009.

[94] A. Ojala, “Adjusting software revenue and pricing strategies in the era of cloud computing,” *Journal of Systems and Software*, vol. 122, pp. 40-51, 2016.

[95] S. Ding, C. Xia, Q. Cai, K. Zhou, and S. Yang, “QoS-aware resource matching and recommendation for cloud computing systems,” *Applied Mathematics and Computation*, vol. 247, pp. 941-950, 2014.

[96] Y. Wang, J. Zhou, L. I. Xinyuan, and X. Song, “Grouping users using a combination-based clustering algorithm in the service environment,” In 2017 IEEE International Conference on Web Services (ICWS), *IEEE*, pp. 721-727, 2017.

[97] L. Du, M. Nunez, and X. Bai, “Leveraging Slack Capacity in IaaS Contract Cloud Services,” Available at SSRN 2665796, 2015.

[98] A. Aleem and C. R. Sprott, “Let me in the cloud: analysis of the benefit and risk assessment of cloud platform,” *Journal of Financial Crime*, vol. 20, no. 1, pp. 6-24, 2013.

[99] S. B. Rahi, S. Bisui, and S. C. Misra, “Identifying critical challenges in the adoption of cloud-based services,” *International Journal of Communication Systems*, vol. 30, no. 12, e3261, 2017.

[100] S. Tripathi and J. Nasina, “Adoption of cloud computing in business: a multi-case approach to evaluate fit viability model (FVM),” *International Journal of Business and Information*, vol. 12, no. 1, 2017.

[101] S. Tripathi, “Determinants of cloud computing intentions to use: role of firm’s size, managerial structure and industrial sector,” *Journal of International Technology and Information Management*, vol. 28, no. 2, pp. 51-92, 2019.

[102] E. Meijer, “All your database are belong to us,” *Communications of the ACM*, vol. 55, no. 9, pp. 54-60, 2012.

[103] W. Lehner and K. U. Sattler, “Data Cloudification,” In Web-Scale Data Management for the Cloud Springer, New York, pp. 1-12, 2013.

[104] J. Rong, T. Qin, and B. An, “Competitive cloud pricing for long-term revenue maximization,” *Journal of Computer Science and Technology*, vol. 34, no. 3, pp. 645-656, 2019.

[105] S. Adabi, F. Alayin, and A. Sharifi, “A new flexible pricing mechanism considering price–quality relation for cloud resource allocation,” *Evolving Systems*, pp. 1-25, 2019.

[106] F. Sheikholeslami and N. Jafari, “Auction-based resource allocation mechanisms in the cloud environments: a review of the literature and reflection on future challenges,” *Concurrency and Computation: Practice and Experience*, vol. 30, no. 16, 2018.

[107] A. Elhabbash, F. Samreen, J. Hadley, and Y. Elkhatib, “Cloud brokerage: A systematic survey,” *ACM Computing Surveys (CSUR)*, vol. 51, no. 6, pp. 1-28, 2019.

[108] E. Azhir, N. J. Navimipour, M. Hosseinzadeh, A. Sharifi, and A. Darwesh, “Query optimization mechanisms in the cloud environments: A systematic study,” *International Journal of Communication Systems*, vol. 32, no. 8, e3940, 2019.

[109] M. Macías and J. Guitart, “A genetic model for pricing in cloud computing markets,” In Proceedings of the 2011 ACM Symposium on Applied Computing. TaiChung, Taiwan. ACM, pp. 113-118, 2011.

[110] J. Mei, K. Li, A. Ouyang, and K. Li, “A profit maximization scheme with guaranteed quality of service in cloud computing,” *IEEE Transactions on Computers*, vol. 64, no. 11, pp. 3064-3078, 2015.

[111] X., Wang, H. Che, K. Li, M. Huang, and C. Gao, “An intelligent economic approach for dynamic resource allocation in cloud services,” *IEEE transactions on cloud computing*, vol. 3, no. 3, pp. 275-289, 2015.

[112] L. Friedman, “Game-theory models in the allocation of advertising expenditures,” *Operations research*, vol. 6, no. 5, pp. 699-709, 1958.

[113] A. Mas-Colell, M. D. Whinston, and J. R. Green, Microeconomic theory, New York: Oxford university press, vol. 1, 1995.

[114] R. B. Myerson, Game theory, Harvard university press, 2013.

[115] S. Tadelis, Game theory: an introduction, Princeton university press, 2013.

[116] K. Chatterjee and W. Samuelson, Game theory and business applications, Springer, 2014.

[117] E., Dekel and M. Siniscalchi, “Epistemic game theory,” In Handbook of Game Theory with Economic Applications, Elsevier, vol. 4, pp. 619-702, 2015.

[118] R. P. McAfee and J. McMillan, “Competition and game theory,” *Journal of marketing research*, vol. 33, no. 3, pp. 263-267, 1996.

[119] M. G. Bell, “A game theory approach to measuring the performance reliability of transport networks,” *Transportation Research Part B: Methodological*, vol. 34, no. 6, pp. 533-545, 2000.

[120] M. Esmaeili, M. B. Aryanezhad, and P. Zeephongsekul, “A game theory approach in seller–buyer supply chain,” *European Journal of Operational Research*, vol. 195, no. 2, pp. 442-448, 2009.

[121] R. B. Myerson, “Nash equilibrium and the history of economic theory,” *Journal of Economic Literature*, vol. 37, no. 3, pp. 1067-1082, 1999.

[122] E. Maskin, “Nash equilibrium and welfare optimality,” *The Review of Economic Studies*, vol. 66, no. 1, pp. 23-38, 1999.

[123] E. Van Damme, Stability and perfection of Nash equilibria, Berlin: Springer-Verlag, vol. 339, 1991.

[124] C. Daskalakis, P. W. Goldberg, and C. H. Papadimitriou, “The complexity of computing a Nash equilibrium,” *SIAM Journal on Computing*, vol. 39, no. 1, pp. 195-259, 2009.

[125] H. Konishi, M. Le Breton, and S. Weber, “Pure strategy Nash equilibrium in a group formation game with positive externalities,” *Games and Economic Behavior*, vol. 21, no. 1-2, pp. 161-182, 1997.

[126] E. Maskin, “Commentary: Nash equilibrium and mechanism design,” *Games and Economic Behavior*, vol. 71, no. 1, pp. 9-11, 2011.

[127] R. P. McAfee, and J. McMillan. “Auctions and bidding,” *Journal of economic literature*, vol. 25, no. 2, pp. 699-738, 1987.

[128] Y. Shoham and K. Leyton-Brown, “Multiagent systems: Algorithmic, game-theoretic, and logical foundations,” Cambridge University Press, 2008.

[129] D. M. Kreps, “Game theory and economic modelling,” Oxford University Press, 1990.

[130] R. B. Myerson, and M. A. Satterthwaite. “Efficient mechanisms for bilateral trading,” *Journal of economic theory*, vol. 29, no. 2, pp. 265-281, 1983.

[131] J. Bulow and J. Roberts, “The simple economics of optimal auctions,” *Journal of political economy*, vol. 97, no. 5, pp. 1060-1090, 1989.

[132] R. Wilson, “Strategic analysis of auctions,” *Handbook of game theory with economic applications*, vol. 1, pp. 227-279, 1992.

[133] W. Vickrey, “Counter speculation, auctions, and competitive sealed tenders,” *The Journal of finance*, vol. 16, no. 1, pp. 8-37, 1961.

[134] R. B. Myerson, “Optimal auction design,” *Mathematics of operations research*, vol. 6, no. 1, pp. 58-73, 1981.

[135] T. Roughgarden, “Algorithmic game theory,” *Communications of the ACM*, vol. 53, no. 7, pp. 78-86, 2010.

[136] K. Chatterjee and W. Samuelson. “Bargaining under Incomplete Information,” *Operations Research*, vol. 31, no. 5, pp. 835-851, 1983.

[137] S. Alaei, "Bayesian combinatorial auctions: expanding single buyer mechanisms to many buyers," *SIAM Journal on Computing*, vol. 43, no. 2, pp. 930-972, 2014.

[138] D. Friedman, "The double auction market institution: A survey," *The double auction market: Institutions, theories, and evidence*, vol. 14, pp. 3-25, 1993.

[139] M. Asunción and S. Yago, "Understanding Auctions," Springer, New York, NY, pp. 25, 2015.

[140] G. Guillermo and V. R. Garrett, "Optimal dynamic pricing of inventories with stochastic demand over finite horizons," *Manage. Sci.*, vol.40, no. 8, pp. 999–1020, 1994.

[141] G. Gallego and G. Van Ryzin, "A multiproduct dynamic pricing problem and its applications to network yield management," *Operations research*, vol. 45, no. 1, pp. 24-41, 1997.

[142] W. Zhao and Y. S. Zheng, "Optimal dynamic pricing for perishable assets with nonhomogeneous demand," *Management science*, vol. 46, no. 3, pp. 375-388, 2000.

[143] N. Nisan, T. Roughgarden, E. Tardos, and V. V. Vazirani, "Algorithmic game theory." Cambridge: Cambridge University Press, 2007.

[144] S. Chen, H. Lee, and K. Moinzadeh, "Pricing schemes in cloud computing: utilization-based vs. reservation-based," *Prod. Operat. Manag.*, vol. 28, no.1, pp.82–102. 2019.

[145] X. V. Doan, X. Lei, and S. Shen, "Pricing of reusable resources under ambiguous distributions of demand and service time with emerging applications," *European Journal of Operational Research*, vol. 282, no. 1, pp. 235-251, 2020.

[146] J. Zhang and A. Seidmann, “Perpetual versus subscription licensing under quality uncertainty and network externality effects,” *Journal of management information systems*, vol 27, no. 1, pp. 39-68, 2010.

[147] M. F., Niculescu and D. J. Wu, “Economics of free under perpetual licensing: Implications for the software industry,” *Information Systems Research*, vol. 25, no. 1, pp. 173-199, 2014.

[148] H. Feng, Z. Jiang, and D. Liu, “Quality, pricing, and release time: optimal market entry strategy for new software-as-a-service vendors,” *MIS Quarterly*, vol. 42, no. 1, pp. 333-353, 2017.

[149] K. Jia, X. Liao, and J. Feng, “Selling or leasing? Dynamic pricing of software with upgrades,” *European Journal of Operational Research*, vol. 266, no. 3, pp. 1044-1061, 2018.

[150] C. Weinhardt, A. Anandasivam, B. Blau, N. Borissov, T. Meinl, W. Michalk, and J. Stößer, “Cloud computing–a classification, business models, and research directions,” *Business & Information Systems Engineering*, vol. 1, no.5, pp. 391-399, 2009.

[151] M. Walterbusch, B. Martens, and F. Teuteberg, “A decision model for the evaluation and selection of cloud computing services: a first step towards a more sustainable perspective,” *International Journal of Information Technology & Decision Making*, vol. 14, no.02, pp. 253-285, 2015.

[152] G. Laatikainen and A. Ojala, “SaaS architecture and pricing models,” In 2014 IEEE International Conference on Services Computing, *IEEE*, pp. 597-604, 2014.

[153] L. Youseff, M. Butrico, and D. Da Silva, “Toward a unified ontology of cloud computing,” In IEEE Grid Computing Environments Workshop, *IEEE*, pp. 1-10, 2008.

[154] M. Mihailescu and Y. M. Teo, “Dynamic resource pricing on federated clouds,” Proc. 10th IEEE/ACM Int. Symp. on Cluster Cloud and Grid Computing, 2010.

[155] W. Wei, X. Fan, H. Song, X. Fan, and J. Yang, “Imperfect information dynamic stackelberg game-based resource allocation using hidden Markov for cloud computing,” *IEEE Transactions on Services Computing*, vol. 11, no. 1, pp. 78-89, 2016.

[156] A. S. Prasad and S. Rao, “A mechanism design approach to resource procurement in cloud computing,” *IEEE Transactions on Computers*, vol. 63, no. 1, pp. 17-30, 2013.

[157] H. Roh, C. Jung, W. Lee, and D. Z. Du, “Resource pricing game in geo-distributed clouds,” In 2013 Proceedings IEEE INFOCOM, *IEEE*, pp. 1519-1527, 2013.

[158] T. Truong-Huu and C. K. Tham, “A novel model for competition and cooperation among cloud providers,” *IEEE Trans. Cloud Comput*., vol. 2, no. 3, pp. 251–265, 2014.

[159] S. Mazumdar, A. Scionti, and A. S. Kumar, “Adaptive resource allocation for load balancing in cloud,” In Cloud Computing Springer, Cham, pp. 301-327, 2017.

[160] B. Sharma, R. K. Thulasiram, P. Thulasiraman, S. K. Garg, and R. Buyya, “Pricing cloud compute commodities: a novel financial economic model,” Proc. of IEEE/ACM Int. Symp. on Cluster, Cloud and Grid Computing, 2012.

[161] A. N. Toosi, K. Vanmechelen, K. Ramamohanarao, and R. Buyya, “Revenue maximization with optimal capacity control in infrastructure as a service cloud markets,” *IEEE Trans. Cloud Comput.*, vol. 3, no. 3, pp. 261–274, 2015.

[162] P. R. Milgrom, and R. J. Weber, “A theory of auctions and competitive bidding,” *Econometrica: Journal of the Econometric Society*, vol. 50, no. 5, pp. 1089-1122, 1982.

[163] R. J. Kauffman and E. A. Walden, “Economics and electronic commerce: Survey and directions for research,” *International journal of electronic commerce*, vol. 5, no. 4, pp. 5-116, 2001.

[164] E. J. Pinker, A. Seidmann, and Y. Vakrat, “Managing online auctions: current business and research issues,” *Management science*, vol. 49, no. 11, pp. 1457-1484, 2003.

[165] X. W. Wang, X. Y. Wang, and M. Huang. “A resource allocation method based on the limited english combinatorial auction under cloud computing environment,” In Fuzzy Systems and Knowledge Discovery (FSKD), 9th International Conference. Sichuan, China, pp. 905-909, 2012.

[166] R. A. Sabzevari and E. B. Nejad, “Double combinatorial auction based resource allocation in cloud computing by combinational using of ICA and genetic algorithms,” *International Journal of Computer Applications*, vol. 110, no. 12, 2015.

[167] W. Wang, B. Liang, and B. Li. “Revenue maximization with dynamic auctions in iaas cloud markets,” In Quality of Service (IWQoS), IEEE/ACM 21st International Symposium. Montreal, Canada, pp. 1-6, 2013.

[168] M. Abundo, V. Di Valerio, V. Cardellini, and F. L. Presti, “Bidding strategies in QoS-aware cloud systems based on N-armed bandit problems,” In 2014 IEEE 3rd Symposium on Network Cloud Computing and Applications, pp. 38-45, *IEEE*, 2014.

[169] T. O. Omotehinwa and J. S. Sadiku, “A dynamic strategy-proof algorithm for allocation and pricing of cloud services,” *International Journal of Cloud Computing*, vol. 8, no. 2, pp. 166-182, 2019.

[170] S. Shang, J. Jiang, Y. Wu, Z. Huang, G. Yang, and W. Zheng, "DABGPM: a double auction bayesian game-based pricing model in cloud market," *Network and Parallel Computing*, pp. 155-164, 2010.

[171] C., Chawla and I. Chana, "Day-ahead pricing model for smart cloud using time dependent pricing," *International Journal of Computer Network and Information Security*, vol. 7, no. 11, pp. 9, 2015.

[172] W.-Y. Lin, G.-Y. Lin, and H.-Y. Wei, "Dynamic auction mechanism for cloud resource allocation," in Cluster, Cloud and Grid Computing (CCGrid), 10th IEEE/ACM International Conference on, 2010.

[173] G. Baranwal and D. P. Vidyarthi, "A truthful and fair multi-attribute combinatorial reverse auction for resource procurement in cloud computing," *IEEE Transactions on Services Computing*, 2016.

[174] Q. Wang, B. Ye, B. Tang, S. Guo, and S. Lu, "eBay in the clouds: false-name-proof auctions for cloud resource allocation," In 2015 IEEE 35th International Conference on Distributed Computing Systems, *IEEE*, pp. 153-162, 2015.

[175] I. Fujiwara, K. Aida, and I. Ono, "Applying double-sided combinational auctions to resource allocation in cloud computing," in 10th Annual International Symposium on Applications and the Internet, 2010.

[176] A. Bandyopadhyay, S. Mukhopadhyay, and U. Ganguly, "On free of cost service distribution in cloud computing," In 2017 International Conference on Advances in Computing, Communications and Informatics (ICACCI), *IEEE*, pp. 1974-1980, 2017.

[177] M. Hosseinpour, A. Yari, and H. Nasiriasayesh, “Continuous double auction scheduling in federated cloud services,” *International Journal of Information and Communication Technology Research*, vol. 11, no. 1, pp. 19-26, 2019.

[178] S. Zaman and D. Grosu. “Combinatorial auction-based allocation of virtual machine instances in clouds,” *Journal of Parallel and Distributed Computing*, vol. 73, no. 4, pp. 495-508, 2013.

[179] G. Di Modica, G. Petralia, and O. Tomarchio, “Procurement auctions to trade computing capacity in the cloud,” In 2013 Eighth International Conference on P2P, Parallel, Grid, Cloud and Internet Computing, *IEEE*, pp. 298-305, 2013.

[180] S. Chichin, Q. B. Vo, and R. Kowalczyk, “Double-sided market mechanism for trading cloud resources,” In 2015 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT), *IEEE*, Vol. 2, pp. 198-205, 2015.

[181] A. Salehan, H. Deldari, and S. Abrishami, “An online valuation-based sealed winner-bid auction game for resource allocation and pricing in clouds,” *The Journal of Supercomputing*, vol.73, no. 11, pp. 4868-4905, 2017.

[182] P. Samimi, Y. Teimouri, and M. Mukhtar, “A combinatorial double auction resource allocation model in cloud computing,” *Information Sciences*, vol. 357, pp. 201-216, 2016.

[183] R. Bhan, A. Singh, R. Pamula, and P. Faruki, “Auction based scheme for resource allotment in cloud computing,” In Digital Business Springer, Cham, pp. 119-141, 2019.

[184] R. Singhal and A. Singhal, "A combinatorial economical double auction resource allocation model (CEDARA)," In 2019 International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (COMITCon), *IEEE*, pp. 497-502, 2019.

[185] S. Padmavathi, P. K. Soniha, N. Soundarya, and S. Srimathi, "Dynamic resource provisioning and monitoring for cloud computing," In 2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS), *IEEE*, pp. 1-6, 2017.

[186] G. Baranwal, D. Kumar, Z. Raza, and D. P. Vidyarthi, "A negotiation based dynamic pricing heuristic in cloud computing," *International Journal of Grid and Utility Computing*, vol. 9, no. 1, pp. 83-96, 2018.

[187] D. Kumar, G. Baranwal, Z. Raza, and D. P. Vidyarthi, "A truthful combinatorial double auction-based marketplace mechanism for cloud computing," *Journal of Systems and Software*, vol. 140, pp. 91-108, 2018.

[188] D. Kumar, G. Baranwal, Z. Raza, and D. P. Vidyarthi, "A systematic study of double auction mechanisms in cloud computing," *Journal of Systems and Software*, vol. 125, pp. 234-255, 2017.

[189] G. Portella, G. N. Rodrigues, E. Nakano, and A. C. Melo, "Statistical analysis of Amazon EC2 cloud pricing models," *Concurrency and Computation: Practice and Experience*, vol. 31, no. 18, 2019.

[190] N. Dimitri, "Pricing cloud IaaS computing services," *Journal of Cloud Computing*, vol. 9, no. 1, pp. 1-11, 2020.

[191] G. Portella, E. Nakano, G. N. Rodrigues, and A. C. Melo, "Utility-based strategy for balanced cost and availability at the cloud spot market," In 2019 IEEE 12th International Conference on Cloud Computing (CLOUD), *IEEE*, pp. 214-218, 2019.

[192] P. C. Cramton, S. Yoav, and S. Richard, "Combinatorial auctions," MIT Press, pp. 30, 2006.

[193] D. C. Parkes, "Iterative combinatorial auctions," MIT press, 2006.

[194] R. Holzman and D. Monderer, "Characterization of ex post equilibrium in the VCG combinatorial auctions," *Games and Economic Behavior*, vol. 47, no. 1, pp. 87-103, 2004.

[195] N. Nisan, "Bidding and allocation in combinatorial auctions," In Proceedings of the 2nd ACM conference on Electronic commerce, pp. 1-12, 2000.

[196] L. Blumrosen and N. Nisan, "Combinatorial auctions," *Algorithmic game theory*, vol. 267, pp. 300, 2007.

[197] A. Pekeč and M. H. Rothkopf, "Combinatorial auction design," *Management Science*, vol. 49, no. 11, pp. 1485-1503, 2003.

[198] G. V. Prasad, A. S. Prasad, and S. Rao, "A combinatorial auction mechanism for multiple resource procurement in cloud computing," *IEEE Transactions on Cloud Computing*, vol. 6, no.4, pp. 904-914, 2016.

[199] E. Filiopoulou, P. Mitropoulou, A. Tsadimas, C. Michalakelis, M. Nikolaidou, and D. Anagnostopoulos, "Integrating cost analysis in the cloud: a SoS approach," In *2015 11th International Conference on Innovations in Information Technology (IIT)*, *IEEE*, pp. 278-283, 2015.

[200] L. Xu, J. Wang, A. Nallanathan, and Y. Li, "Resource allocation based on double auction for cloud computing system," In 2016 IEEE 18th International Conference on High Performance Computing and Communications; IEEE 14th International Conference on Smart City; IEEE 2nd International Conference on Data Science and Systems (HPCC/SmartCity/DSS), *IEEE*, pp. 1538-1543, 2016.

[201] Y. Zhang, K. Xu, X. Shi, H. Wang, J. Liu, and Y. Wang, "Design, modeling, and analysis of online combinatorial double auction for mobile cloud computing markets," *International Journal of Communication Systems*, vol. 31, no. 7, 2018.

[202] H. Xu and B. Li, "Dynamic cloud pricing for revenue maximization," *IEEE Trans. Cloud Comput.*, vol. 1, no. 2, pp. 158-171, 2013.

[203] M., Aazam and E. N. Huh, "Cloud broker service-oriented resource management model," *Transactions on Emerging Telecommunications Technologies*, vol. 28, no. 2, e2937, 2017.

[204] F. Alzhouri and A. Agarwal, "Dynamic pricing scheme: towards cloud revenue maximization," In 2015 IEEE 7th International Conference on Cloud Computing Technology and Science (CloudCom), *IEEE*, pp. 168-173, 2015.

[205] P. Wang, Y. Qi, D. Hui, L. Rao, and X. Liu, "Present or future: optimal pricing for spot instances," In IEEE 33rd International Conference on Distributed Computing Systems, *IEEE*, pp. 410-419, 2013.

[206] Z. Li, W. Tarneberg, M. Kihl, and A. Robertsson, "Using a predator-prey model to explain variations of cloud spot price," arXiv preprint arXiv:1708.01397, 2017.

[207] A. K. Mishra, B. K. Umrao, and D. K. Yadav, “A survey on optimal utilization of preemptible VM instances in cloud computing,” *The Journal of Supercomputing*, vol. 74, no. 11, pp. 5980-6032, 2018.

[208] Y. Zhang, A. Ghosh, and V. Aggarwal, “Optimized Portfolio Contracts for Bidding the Cloud,” *IEEE Transactions on Services Computing*, 2018.

[209] V. K. Singh and K. Dutta, “Dynamic price prediction for amazon spot instances,” In 48th Hawaii International Conference on System Sciences, pp. 1513-1520, 2015.

[210] C. Wang, Q. Liang, and B. Urgaonkar, “An empirical analysis of amazon ec2 spot instance features affecting cost-effective resource procurement,” *ACM Transactions on Modeling and Performance Evaluation of Computing Systems (TOMPECS)*, vol. 3, no. 2, pp. 1-24, 2018.

[211] V. Khandelwal, A. Chaturvedi, and C. P. Gupta, “Amazon EC2 spot price prediction using regression random forests,” *IEEE Transactions on Cloud Computing*, 2017.

[212] Q. Zhang, Q. Zhu, and R. Boutaba, “Dynamic resource allocation for spot markets in cloud computing environments,” In the Fourth IEEE International Conference on Utility and Cloud Computing, *IEEE*, pp. 178-185, 2011.

[213] N. Krishnaveni and G. Sivakumar, “Survey on dynamic resource allocation strategy in cloud computing environment,” *International Journal of Computer Applications Technology and Research*, vol. 2, no. 6, pp. 731-737, 2013.

[214] K. Song, Y. Yao, and L. Golubchik, “Exploring the profit-reliability trade-off in amazon's spot instance market: A better pricing mechanism,” In 2013 IEEE/ACM 21st International Symposium on Quality of Service (IWQoS), *IEEE*, pp. 1-10, 2013.

[215] R. M. Wallace, V. Turchenko, M. Sheikhalishahi, I. Turchenko, V. Shults, J. L. Vazquez-Poletti, and L. Grandinetti, “Applications of neural-based spot market prediction for cloud computing,” In IEEE 7th International Conference on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS), vol. 2, pp. 710-716, 2013.

[216] R., Keller, L., Häfner, T., Sachs, and G. Fridgen, “Scheduling flexible demand in cloud computing spot markets,” *Business & Information Systems Engineering*, vol. 62, no. 1, pp. 25-39, 2020.

[217] V. Khandelwal, C. P. Gupta, and A. K. Chaturvedi, “Perceptive bidding strategy for Amazon EC2 spot instance market,” *Multiagent and Grid Systems*, vol. 14, no. 1, pp. 83-102, 2018.

[218] M. B. Chhetri, M. Lumpe, Q. B. Vo, and R. Kowalczyk, “On estimating bids for amazon ec2 spot instances using time series forecasting,” In 2017 IEEE International Conference on Services Computing (SCC), *IEEE*, pp. 44-51,2017.

[219] Y. Hu, “A game-based virtual machine pricing mechanism in federated clouds,” *International Journal of Intelligent Systems Technologies and Applications*, vol. 18, no. 6, pp. 606-622, 2019.

[220] Y. Wang, J. Zhou, J. Liu, G. Xu, and X. Song, “Research on QoS optimization method of cloud service based on utility game between users and service providers in the cloud market,” In 2017 IEEE International Conference on Services Computing (SCC), *IEEE*, pp. 297-304, 2017.

[221] P. Cong, G. Xu, T. Wei, and K. Li, “A survey of profit optimization techniques for cloud providers,” *ACM Computing Surveys (CSUR)*, vol. 53, no. 2, pp. 1-35, 2020.

[222] X. Zheng, L. D. Xu, and S. Chai, "QoS recommendation in cloud services." *IEEE Access*, vol. 5, pp. 5171-5177, 2017.

[223] X. Zhang, Z. Huang, C. Wu, Z. Li, and F. C. Lau, "Online auctions in IaaS clouds: welfare and profit maximization with server costs," *IEEE/ACM Transactions on Networking*, vol. 25, no. 2, pp. 1034-1047, 2016.

[224] K. He, C. Huang, Z. Li, A. Shi, and J. Shi, "An online auction for deadline-aware dynamic cloud resource provisioning," In 2016 IEEE 22nd International Conference on Parallel and Distributed Systems (ICPADS), *IEEE*, pp. 677-684, 2016.

[225] M. Khodak, L. Zheng, A. S. Lan, C. Joe-Wong, and M. Chiang, "Learning cloud dynamics to optimize spot instance bidding strategies," In IEEE INFOCOM 2018-IEEE Conference on Computer Communications, *IEEE*, pp. 2762-2770, 2018.

[226] X. Wu and J. Han, "Auction-Based Cloud Service Pricing and Penalty with Availability on Demand," *Information*, vol. 9, no. 4, pp. 87, 2018.

[227] B. Wei, C. Lin, and X. Kong, "Dependability modeling and analysis for the virtual data center of cloud computing," In 2011 IEEE International Conference on High Performance Computing and Communications, *IEEE*, pp. 784-789, 2011.

[228] Y. Pan and N. Hu, "Research on dependability of cloud computing systems," In 2014 10th International Conference on Reliability, Maintainability and Safety (ICRMS), *IEEE*, pp. 435-439, 2014.

[229] S. Bhattacharjee and B. Annappa, "Enhancing reliability of cloud system through proactive identification of under performing components," In 2016 International Conference on Advanced Communication Control and Computing Technologies (ICACCCT), *IEEE*, pp. 522-526, 2016.

[230] M. Jammal, A. Kanso, P. Heidari, and A. Shami, "A formal model for the availability analysis of cloud deployed multi-tiered applications," In 2016 IEEE International Conference on Cloud Engineering Workshop (IC2EW), *IEEE*, pp. 82-87, 2016.

[231] Y. Lu, X. Zheng, L. Li, and L. D. Xu, "Pricing the cloud: a QoS-based auction approach," *Enterprise Information Syst.*, vol. 14, no. 3, pp. 334-351, 2019.

[232] X. Zheng, P. Martin, K. Brohman, and L. D. Xu. "CLOUDQUAL: a quality model for cloud services," *IEEE transactions on industrial informatics*, vol. 10, no. 2, pp. 1527-1536, 2014.

[233] H. Li, J. Liu, and G. Tang, "A pricing algorithm for cloud computing resources," Proc. Int. Conference on Network Computing and Inform. Security, 2011.

[234] B. El Zant and M. Gagnaire, "Dynamic break-even pricing for cloud federation," In 2014 IEEE Globecom Workshops (GC Wkshps), *IEEE*, pp. 70-74, 2014.

[235] E. D., Raj and L. D. Babu, "Issues in on-demand cloud-based gaming storage: quality of service and quality of experience," In Emerging Technologies and Applications for Cloud-Based Gaming, IGI Global, pp. 115-138, 2017.

[236] A. Y. Du, S. Das, and R. Ramesh, "Efficient risk hedging by dynamic forward pricing: a study in cloud computing," *INFORMS Journal on Computing*, vol. 25, no. 4, pp. 625-642, 2012.

[237] S. Ding, S. Yang, Y. Zhang, C. Liang, and C. Xia, "Combining QoS prediction and customer satisfaction estimation to solve cloud service trustworthiness evaluation problems," *Knowledge-Based Systems*, vol. 56, pp. 216-225, 2014.

[238] P. Konana, A. Gupta, and A. B. Whinston, "Integrating user preferences and real-time workload in information services," *Information Systems Research*, vol. 11, no. 2, pp. 177-196, 2000.

[239] Y. M. Li, "Pricing digital content distribution over heterogeneous channels," *Decision Support Systems*, vol. 50, no. 1, pp. 243-257, 2010.

[240] A. Rai, "Editor's comments: diversity of design science research," *MIS Quarterly*, vol. 41, no. 1, pp. iii-xviii, 2017.

[241] D. Lehmann, L. I. Oćallaghan, and Y. Shoham, "Truth revelation in approximately efficient combinatorial auctions," *Journal of the ACM (JACM)*, vol. 49, no. 5, pp. 577-602, 2002.

[242] D. Lehmann, R. Müller, and T. Sandholm, "The winner determination problem," *Combinatorial auctions*, pp. 297-318, 2006.

[243] A. Kothari, D. C. Parkes, and S. Suri, "Approximately-strategy proof and tractable multiunit auctions," *Decision Support Systems*, vol. 39, no. 1, pp. 105-121, 2005.

[244] R. Holzman, N. Kfir-Dahav, D. Monderer, and M. Tennenholtz, "Bundling equilibrium in combinatorial auctions," *Games and Economic Behavior*, vol. 47, no. 1, pp. 104-123, 2004.

[245] Q. Wang, K. Ren, and X. Meng, "When cloud meets ebay: towards effective pricing for cloud computing," In 2012 Proceedings IEEE INFOCOM, *IEEE*, pp. 936-944, 2012.

[246] S. Zaman and D. Grosu, "A combinatorial auction-based mechanism for dynamic VM provisioning and allocation in clouds," *IEEE Transactions on Cloud Computing*, vol. 1, no. 2, pp. 129-141, 2013.

[247] D.A. Battleson, B.C. West, J. Kim, B. Ramesh, and P.S. Robinson, "Achieving dynamic capabilities with cloud computing: an empirical investigation," *European Journal of Information Systems*, vol. 25, no. 3, pp. 209–230, 2016.

[248] X. Luo, W. Zhang, R. Bose, H. Li, and Q. B. Chung, "Producing competitive advantage from an infrastructure technology: the case of cloud computing," *Information Systems Management*, vol. 35, no. 2, pp. 147-160, 2018.

[249] A. Ali, D. Warren, and L. Mathiassen, "Cloud-based business services innovation: A risk management model," *International Journal of Information Management*, vol. 37, no. 6, pp. 639-649, 2017.

[250] A. Benlian, W. J. Kettinger, A. Sunyaev, T. J. Winkler, and guest editors, "The transformative value of cloud computing: a decoupling, platformization, and recombination theoretical framework," *Journal of management information systems*, vol. 35, no. 3, pp. 719-739, 2018.

[251] J. Huang, R. J. Kauffman, and D. Ma, "Pricing strategy for cloud computing: A damaged services perspective," *Decision Support Systems*, vol. 78, pp. 80-92, 2015.

[252] I. Lee, "Pricing schemes and profit-maximizing pricing for cloud services," *Journal of Revenue and Pricing Management*, vol. 18, no. 2, pp. 112-122, 2019.

[253] Z. Guo and D. Ma, "A model of competition between perpetual software and software as a service," *MIS Quarterly*, vol. 42, no. 1, pp. 1, 2018.

[254] S. Lei, F. Chen, and M. Li, "Pricing cloud service considering heterogeneous customers," In Proceedings of the 6th International Asia Conference on Industrial Engineering and Management Innovation Atlantis Press, Paris, pp. 1063-1073, 2016.

[255] D. G. Schniederjans and D. N. Hales, "Cloud computing and its impact on economic and environmental performance: A transaction cost economics perspective," *Decision Support Systems*, vol. 86, pp. 73-82, 2016.

[256] S. Liu, F. T. Chan, J. Yang, and B. Niu, "Understanding the effect of cloud computing on organizational agility: an empirical examination," *International Journal of Information Management*, vol. 43, pp. 98-111, 2018.

[257] Y. Roumani and J. K. Nwankpa, "An empirical study on predicting cloud incidents," *International Journal of Information Management*, vol. 47, pp. 131-139, 2019.

[258] P. K. Senyo, E. Addae, & R. Boateng, "Cloud computing research: a review of research themes, frameworks, methods and future research directions," *International Journal of Information Management*, vol. 38, no. 1, pp. 128-139, 2018.

[259] E. Loukis, M. Janssen, and I. Mintchev, "Determinants of software-as-a-service benefits and impact on firm performance," *Decision Support Systems*, vol. 117, pp. 38-47, 2019.

[260] A. Herzfeldt, S. Floerecke, C. Ertl, and H. Krcmar, "Examining the antecedents of cloud service profitability," *International Journal of Cloud Applications and Computing (IJCAC)*, vol. 9, no. 4, pp. 37-65, 2019.

[261] C. Wu, R. Buyya, & K. Ramamohanarao, "Modeling cloud business customers' utility functions," *Future Generation Computer Systems*, vol. 105, pp. 737-753, 2020.

[262] H. Shah-Mansouri, V. W. Wong, and R. Schober, "Joint optimal pricing and task scheduling in mobile cloud computing systems," *IEEE Transactions on Wireless Communications*, vol. 16, no. 8, pp. 5218-5232, 2017.

[263] Y. Lu, "Artificial intelligence: a survey on evolution, models, applications and future trends," *Journal of Management Analytics*, vol. 6, no. 1, pp. 1-29, 2019.

[264] Y. Lu, "Deep learning of data analytics in healthcare," In Theory and Practice of Business Intelligence in Healthcare, IGI Global, pp. 151-165, 2020.

[265] Y. Lu, "Blockchain and the related issues: a review of current research topics," *Journal of Management Analytics*, vol. 5, no. 4, pp. 231-255, 2018.

[266] Y. Lu and X. R. Zheng. "Block Chain Based Double Auction Design," In Proceedings of the AMCIS on Strategic and Competitive Use of Information Technology (SCUIT), New Orleans, 2018.

[267] S. Nakamoto, "Bitcoin: a peer-to-peer electronic cash system," 2008. [Online]. Available: https://bitcoin.org/bitcoin.pdf.

[268] X. Wu, Y. Gu, J. Tao, G. Li, J. Han, and N. Xiong, "An effective data-driven cloud resource procurement scheme with personalized reserve prices," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 2019.

[269] M. Crosby, P. Pattanayak, S. Verma, and V. Kalyanaraman, "Blockchain technology: beyond bitcoin," *Appl. Innovation*, vol. 2, pp. 6-10, 2016.

[270] A. Hughes, A. Park, J. Kietzmann, and C. Archer-Brown, “Beyond Bitcoin: what blockchain and distributed ledger technologies mean for firms,” *Business Horizons*, vol. 62, no. 3, pp. 273-281, 2019.

[271] Z. Zheng, S. Xie, H. N. Dai, X. Chen, and H. Wang, “Blockchain challenges and opportunities: a survey,” *International Journal of Web and Grid Services*, vol. 14, no. 4, pp. 352-375, 2018.

[272] A. Priya, A. Khatri, and P. Dixit, “Rise of blockchain technology: beyond cryptocurrency,” In International Conference on Application of Computing and Communication Technologies Springer, Singapore, pp. 286-299, 2018.

[273] M. Pilkington, “Blockchain technology: principles and applications,” In Handbook of Research on Digital Transformations, Edward Elgar Publishing, Cheltenham, UK, Northampton, MA, USA, Chapter 11, pp. 225-265, 2016,

[274] Y. Lu, “The Blockchain: State-of-the-Art and Research Challenges,” *Journal of Industrial Information Integration*, 2019. Early Access. doi.org/10.1016/j.jii. 2019.04.00.

[275] Y. Lu, “Blockchain: A survey on Functions, Applications and Open Issues,” *Journal of Industrial Integration and Management*, vol. 3, no. 04, pp. 1850015, 2018.

[276] J. Al-Jaroodi and N. Mohamed, “Blockchain in industries: a survey,” *IEEE Access*, vol. 7, pp. 36500-36515, 2019.

[277] W. Viriyasitavat, L. D. Xu, Z. Bi, D. Hoonsopon, and N. Charoenruk, “Managing QoS of Internet-of-Things services using Blockchain,” *IEEE Transactions on Computational Social Systems*, vol. 6, no. 6, pp. 1357-1368, 2019.

[278] Z. Zheng, S. Xie, H. Dai, X. Chen, and H. Wang, "An overview of blockchain technology: Architecture, consensus, and future trends," In 2017 IEEE International Congress on Big Data (BigData Congress), *IEEE*, pp. 557-564, 2017.

[279] T. McGhin, K. K. R. Choo, C. Z. Liu, and D. He, "Blockchain in healthcare applications: Research challenges and opportunities," *Journal of Network and Computer Applications*, 2019.

[280] Z. Liu, N. C. Luong, W. Wang, D. Niyato, P. Wang, Y. C. Liang, and D. I. Kim, "A survey on applications of game theory in blockchain," arXiv preprint arXiv:1902.10865, 2019.

[281] K. N. Khaqqi, J. J. Sikorski, K. Hadinoto, and M. Kraft, "Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application," *Applied Energy*, vol. 209, pp. 8-19, 2018.

[282] A. Lei, H. Cruickshank, Y. Cao, P. Asuquo, C. P. A. Ogah, and Z. Sun, "Blockchain-based dynamic key management for heterogeneous intelligent transportation systems," *IEEE Internet of Things Journal*, vol. 4, no. 6, pp. 1832-1843, 2017.

[283] N. Z. Aitzhan and D. Svetinovic, "Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams," *IEEE Transactions on Dependable and Secure Computing*, vol. 15, no. 5, pp. 840-852, 2018.

[284] Y. Jiao, P. Wang, D. Niyato, and K. Suankaewmanee, "Auction mechanisms in cloud/fog computing resource allocation for public blockchain networks," *IEEE Transactions on Parallel and Distributed Systems*, vol. 30, no. 9, pp. 1975-1989, 2019.

[285] Z. Liu, N. C. Luong, W. Wang, D. Niyato, P. Wang, Y. C. Liang, and D. I. Kim, "A survey on blockchain: A game theoretical perspective," *IEEE Access*, vol. 7, pp. 47615-47643, 2019.

5.3 The Impact of QoS-based Pricing Strategy on Customer Purchasing Behavior

[286] V. Venkatesh, J. Y. Thong, and X. Xu, "Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology," *MIS quarterly*, pp. 157-178, 2012.

[287] J. S. Jasperson, P. E. Carter, and R. W. Zmud, "A comprehensive conceptualization of post-adoptive behaviors associated with information technology enabled work systems," *MIS quarterly*, vol. 29, no. 3, pp. 525-557, 2005.

[288] A. Beaudry and A. Pinsonneault, "The other side of acceptance: studying the direct and indirect effects of emotions on information technology use," *MIS quarterly*, pp. 689-710, 2010.

[289] C. J. Guo, M. Warkentin, X. R. Luo, A. Gurung, and J. P. Shim, "An imposed etic approach with Schwartz polar dimensions to explore cross-cultural use of social network services," *Information & Management*, 103261, 2020.

[290] V. Venkatesh, J. Y. Thong, and X. Xu, "Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology," *MIS quarterly*, pp. 157-178, 2012.

[291] I. Ajzen, "The theory of planned behavior," *Organizational Behavior and Human Decision Processes*, vol. 50, no. 2, pp. 179-211, 1991.

[292] W. W. Chin, B. L. Marcolin, and P. R. Newsted, "A partial least squares latent variable modeling approach for measuring interaction effects: results from a monte carlo simulation study and an electronic-mail emotion/adoption study," *Information Systems Research*, vol. 14, no. 2, pp. 189-217, 2003.

[293] L. M. Hitt, and P. Y. Chen, “Bundling with customer self- selection: a simple approach to bundling low-marginal-cost goods,” *Management Science*, vol. 51, no. 10, pp. 1481-1493, 2005.

[294] A. S. Notani, “Moderators of perceived behavioral control’s predictiveness in the theory of planned behavior: a meta- analysis,” *Journal of Consumer Psychology*, vol. 7, no. 3, pp. 247-271, 1998.

[295] G. Hofstede, “Culture and organizations,” *International Studies of Management & Organization*, vol. 10, no. 4, pp. 15-41, 1980.

[296] G. Hofstede, “The cultural relativity of organizational practices and theories,” *Journal of international business studies*, vol. 14, no. 2, pp. 75-89, 1983.

[297] C. J. Guo, M. Warkentin, X. R. Luo, A. Gurung, and J. P. Shim, “An imposed etic approach with Schwartz polar dimensions to explore cross-cultural use of social network services,” *Information & Management*, publish online, 2020.

[298] S. Dasgupta and B. Gupta, “Espoused organizational culture values as antecedents of internet technology adoption in an emerging economy,” *Information & Management*, vol. 56, no. 6, 103142, 2019.

[299] C. Hsu, Y. T. Lin, and T. Wang, “A legitimacy challenge of a cross-cultural interorganizational information system,” *European Journal of Information Systems*, vol. 24, no. 3, pp. 278-294, 2015.

[300] J. A. Lee, G. N. Soutar, T. M. Daly, and J. J. Louviere, “Schwartz values clusters in the United States and China,” *Journal of Cross-Cultural Psychology*, vol. 42, no. 2, pp. 234-252, 2011.

APPENDICES

A.1 Comparison between Subscription and Pay-Per-Use

The cloud service provider chooses the price mechanism and sets the price, and then customer decides whether to accept it. Since information services usually experience peak periods and idle periods, if customers have different utility functions in different periods, then when cloud service providers choose to price, the price settings will be different. For example, Amazon AWS sets peak and idle periods based on customer demand, and charges different service prices for two different periods. In addition, due to budget constraint and time limitation, for customers, the marginal utility is decreasing, so it can be assumed that there is an upper limit when customers use a certain cloud service. Since cloud service is also an information service, assuming that the marginal cost of cloud service is zero.

The pricing strategy of subscription (fixed pricing strategy) will be employed in the initiating stage. The following steps are the proof of subscription is better than pay-per-use. By this pricing mechanism, cloud providers will have a great chance to attract more potential customers. Due to the price of cloud resources will be lower if providers adopt with subscription as their major pricing strategy.

A.1.1 The Homogeneous Customer

Proposition 1.

If provider adopts with pay-per-use,

The optimal price will be:

$$P_{(D+)} = \frac{a}{X_{(i,D+)}^{MAX}+1} \text{ and } P_{(D-)} = \frac{b}{X_{(i,D-)}^{MAX}+1} \tag{A1-1}$$

And the optimal profit will be:

$$\sum_i \left(a - \frac{a}{X_{(i,D+)}^{MAX}+1} + b - \frac{b}{X_{(i,D-)}^{MAX}+1}\right) - C = \sum_i [a\left(1 - \frac{1}{X_{(i,D+)}^{MAX}+1}\right) + b(1 - \frac{1}{X_{(i,D-)}^{MAX}+1})] - C. \tag{A1-2}$$

Proof of Proposition 1

If pay-per-use is the pricing strategy, $P_{(D+)} > 0, P_{(D-)} > 0$, $P_0 = 0$.

Solve the first derivatives of the optimal price:

$$X_{(i,D+)}^{MAX} = \frac{a}{P_{(D+)}} - 1 \tag{A1-3}$$

$$X_{(i,D-)}^{MAX} = \frac{b}{P_{(D-)}} - 1 \tag{A1-4}$$

Then, the optimal profit is:

$$\sum_i [a\left(1 - \frac{1}{X_{(i,D+)}^{MAX} + 1}\right) + b(1 - \frac{1}{X_{(i,D-)}^{MAX} + 1})] - c \tag{A1-5}$$

Here, because both $X_{(i,D+)}^{MAX}$ and $X_{(i,D-)}^{MAX}$ have boundaries. When $X_{(i,D+)}^{MAX}$ and $X_{(i,D-)}^{MAX}$ are the maximum, the optimal profit will be the highest.

Hence, when $X_{(i,D+)}^{MAX} = \frac{a}{P_{(D+)}} - 1$ and $X_{(i,D-)}^{MAX} = \frac{b}{P_{(D-)}} - 1$, the profit will be maximal as well.

Proposition 2.

If provider adopts with subscription,

the optimal price will be:

$$\mathrm{alog}\big(X_{(i,D+)}^{MAX}+1\big)+b\log X_{(i,D-)}^{MAX}+1) \tag{A1-6}$$

And the optimal profit will be:

$$\sum_i[\mathrm{alog}\big(X_{(i,D+)}^{MAX}+1\big)+b\log(X_{(i,D-)}^{MAX}+1)]-C \tag{A1-7}$$

Proof of Proposition 2

When providers use subscription pricing, consumers choose service portfolio based on demand and pay a fixed price. i.e., $P_{(D+)}=0, P_{(D-)}=0, P_0>0$.

Under this situation, customers would like to choose the maximal purchasing level for both $X_{(i,D+)}^{MAX}$ and $X_{(i,D-)}^{MAX}$. Therefore, the optimal profit will be,

$$\sum_i[\mathrm{alog}\big(X_{(i,D+)}^{MAX}+1\big)+b\log(X_{(i,D-)}^{MAX}+1)]-C \tag{A1-8}$$

In order to optimize the profit, we have,

$$\sum_i[\mathrm{alog}\big(X_{(i,D+)}^{MAX}+1\big)+b\log(X_{(i,D-)}^{MAX}+1)]\geq C \tag{A1-9}$$

So, the optimal price from provider will be $\mathrm{alog}\big(X_{(i,D+)}^{MAX}+1\big)+b\log X_{(i,D-)}^{MAX}+1)$, and the optimal profit will be $\sum_i[\mathrm{alog}\big(X_{(i,D+)}^{MAX}+1\big)+b\log(X_{(i,D-)}^{MAX}+1)]-C$.

Based on Proposition 1 & 2, we have,

$$\mathrm{alog}\big(X_{(i,D+)}^{MAX}+1\big)>1-\frac{1}{X_{(i,D+)}^{MAX}+1}, \text{ and } b\log(X_{(i,D-)}^{MAX}+1)>1-\frac{1}{X_{(i,D-)}^{MAX}+1};$$

And both $X_{(i,D+)}^{MAX}$ and $X_{(i,D-)}^{MAX}$ are greater than 0,

Hence,

$$\mathrm{a}*\log\big(X_{(i,D+)}^{MAX}+1\big)+\mathrm{b}*\log(X_{(i,D-)}^{MAX}+1)>a\left(1+\frac{1}{X_{(i,D+)}^{MAX}+1}\right)+b(1-\frac{1}{X_{(i,D-)}^{MAX}+1})$$

A.1.2 The Heterogeneous Customer

Heterogeneous customers are divided into two categories. The one is divided into luxury customer and poor customer according to the budget constraint (willingness to pay/afford). The other category is divided into high-demand customers and low-demand customers according to the demand level.

I. Luxury and Poor Customers

Proposition 3.

If provider adopts with pay-per-use, when $dX_{(i,D+)}^{MAX} > g$, the optimal price $P_{(D+)} = \frac{a}{X_{(i,D+)}^{MAX}+1}$; when $fX_{(i,D-)}^{MAX} > g$, $P_{(D-)} = \frac{b}{X_{(i,D-)}^{MAX}+1}$. And the optimal profit is:

$$d\left(\frac{a_1 X_{(i,D+)}^{MAX}}{X_{(i,D+)}^{MAX}+1} + \frac{b_1 X_{(i,D-)}^{MAX}}{X_{(i,D-)}^{MAX}+1}\right) + g(a_2 - \frac{a_1}{X_{(i,D+)}^{MAX}+1} + b_2 - \frac{b_2}{X_{(i,D-)}^{MAX}+1}) - C$$

Otherwise, $P_{(D+)} = \frac{a_1}{X_{(i,D+)}^{MAX}+1}$ and $P_{(D-)} = \frac{b_2}{X_{(i,D-)}^{MAX}+1}$. Meanwhile, the optimal profit of provider is:

$$(d+g)\left(\frac{a_1 X_{(i,D+)}^{MAX}}{X_{(i,D+)}^{MAX}+1} + \frac{b_1 X_{(i,D-)}^{MAX}}{X_{(i,D-)}^{MAX}+1}\right) - C$$

Proof of Proposition 3

If pay-per-use is the pricing strategy, $P_{(D+)} > 0, P_{(D-)} > 0$, $P_0 = 0$.

Solve the first derivatives of the optimal price:

$$X_{(1,D+)}^{MAX} = \frac{a_1}{P_{(D+)}} - 1 \tag{A1-10}$$

$$X_{(1,D-)}^{MAX} = \frac{b_1}{P_{(D-)}} - 1 \tag{A1-11}$$

$$X_{(2,D+)}^{MAX} = \frac{a_2}{P_{(D+)}} - 1 \tag{A1-12}$$

$$X_{(2,D-)}^{MAX} = \frac{b_2}{P_{(D-)}} - 1 \tag{A1-13}$$

The optimal profits of provider:

$$d\left(\frac{a_1 X_{(i,D+)}^{MAX}}{X_{(i,D+)}^{MAX} + 1} + \frac{b_1 X_{(i,D-)}^{MAX}}{X_{(i,D-)}^{MAX} + 1}\right) + g(a_2 - \frac{a_1}{X_{(i,D+)}^{MAX} + 1} + b_2 - \frac{b_2}{X_{(i,D-)}^{MAX} + 1}) - C$$

$$\max_{P_{(D+)},P_{(D-)}} d(P_{(D+)} X_{(1,D+)}^{MAX} + P_{(D-)} X_{(1,D-)}^{MAX}) + g\left(P_{(D+)} X_{(2,D+)}^{MAX} + P_{(D-)} X_{(2,D-)}^{MAX}\right) - C$$

$$= \max_{P_{(D+)},P_{(D-)}} d\left(a_1 - P_{(D+)} + b_1 - P_{(D-)}\right) + g(a_2 - P_{(D+)} + b_2 - P_{(D-)})$$

According to Proposition 1, cloud providers need to employ an appropriate pricing to optimize the potential revenues. Let's consider the following function first,

$$\max_{P_{(D+)}} d(P_{(D+)} X_{(1,D+)}^{MAX}) + g\left(P_{(D+)} X_{(2,D+)}^{MAX}\right) = \max_{P_{(D+)}} d\left(a_1 - P_{(D+)}\right) + g(a_2 - P_{(D+)})$$

In order to optimize the above function,

$$\frac{a_2}{X_{(i,D+)}^{MAX} + 1} \leq P_{(D+)} \leq \frac{a_1}{X_{(i,D+)}^{MAX} + 1}$$

Cloud provider is difficult to differentiate different types of customers, they need an identical pricing strategy to optimize their revenues. Meantime, in order to maximize the utility, the luxury customers would like to optimize their demand as $X_{(i,D+)}^{MAX}$, and poor customers' demand will increase because of the decreasing of market price of cloud services. Hence,

$$\max_{P_{(D+)}} d\big(P_{(D+)}X_{(1,D+)}^{MAX}\big) + g\big(P_{(D+)}X_{(2,D+)}^{MAX}\big)$$

$$= \max_{P_{(D+)}} d(P_{(D+)}X_{(1,D+)}^{MAX}) + g\big(a_2 - P_{(D+)}\big) = \max_{P_{(D+)}} ga_2 + (dX_{(1,D+)}^{MAX} - g)P_{(D+)}$$

When $dX_{(1,D+)}^{MAX} > g$, the optimal price when the demand is maximal is $P_{(D+)} = \frac{a_1}{X_{(i,D+)}^{MAX}+1}$, otherwise, $P_{(D+)} = \frac{a_2}{X_{(i,D+)}^{MAX}+1}$.

When $dX_{(1,D-)}^{MAX} > g$, the optimal price when the demand is minimal is $P_{(D-)} = \frac{b_1}{X_{(i,D-)}^{MAX}+1}$, otherwise, $P_{(D-)} = \frac{b_2}{X_{(i,D-)}^{MAX}+1}$.

Proposition 4.

If provider adopts with subscription, the optimal price is:

$a_2\log\big(X_{(i,D+)}^{MAX} + 1\big) + b_2 \log X_{(i,D-)}^{MAX} + 1)$.

And the optimal profit is:

$$(d + g)\left(\frac{a_1 X_{(i,D+)}^{MAX}}{X_{(i,D+)}^{MAX} + 1} + \frac{b_1 X_{(i,D-)}^{MAX}}{X_{(i,D-)}^{MAX} + 1}\right) - C$$

Proof of Proposition 4

According to Proposition 2, cloud provider's asking price to the luxury customer is:

$$a_1\log\big(X_{(i,D+)}^{MAX} + 1\big) + b_1 \log X_{(i,D-)}^{MAX} + 1)$$

Cloud provider's asking price to the poor customer is:

$$a_2\log\big(X_{(i,D+)}^{MAX} + 1\big) + b_2 \log X_{(i,D-)}^{MAX} + 1)$$

Since cloud provider cannot differentiate different types of customers, in order to optimize the revenues, the provider has to hold the luxury customers, not to attract the poor customers. The asking price to both two types of customers should be

$$a_2\log\left(X_{(i,D+)}^{MAX}+1\right)+b_2\log X_{(i,D-)}^{MAX}+1)$$

Also, $a_1 < \frac{d+g}{d}a_2$ and $b_1 < \frac{d+g}{d}b_2$

Then, the optimize profits of provider is:

$$(d+g)\left[a_2\log\left(X_{(i,D+)}^{MAX}+1\right)+b_2\log X_{(i,D-)}^{MAX}+1)\right]-C$$

Because $X_{(i,D+)}^{MAX} \geq 0$ and $X_{(i,D+)}^{MAX} \geq 0$,

$$d\left(\frac{a_1X_{(i,D+)}^{MAX}}{X_{(i,D+)}^{MAX}+1}+\frac{b_1X_{(i,D-)}^{MAX}}{X_{(i,D-)}^{MAX}+1}\right)+g(a_2-\frac{a_1}{X_{(i,D+)}^{MAX}+1}$$

$$+b_2-\frac{a_2}{X_{(i,D+)}^{MA}+1})-C<(d+g)\left[a_2\log\left(X_{(i,D+)}^{MAX}+1\right)+b_2\log X_{(i,D-)}^{MAX}+1)\right]-C$$

Hence, cloud providers could obtain more revenues if they adopt with subscription instead of pay-per-use.

II. High and Low-Demand Customers

Proposition 5.

If provider adopts with pay-per-use, when $gX_{(2,D+)}^{MAX} > d$, the optimal price when demand is high is $P_{(D+)}=\frac{a}{X_{(2,D+)}^{MAX}+1}$; when $gX_{(2,D-)}^{MAX} > d$, the optimal price when demand is low is $P_{(D-)}=\frac{b}{X_{(2,D-)}^{MAX}+1}$. The optimal profit of provider is:

$$(d+g)\left(\frac{aX_{(2,D+)}^{MAX}}{X_{(2,D+)}^{MAX}+1}+\frac{bX_{(2,D-)}^{MAX}}{X_{(2,D-)}^{MAX}+1}\right)-C$$

Otherwise, $P_{(D+)} = \frac{a}{X_{(1,D+)}^{MAX}+1}$ and $P_{(D-)} = \frac{b}{X_{(1,D-)}^{MAX}+1}$. Meanwhile, the optimal profit of provider is:

$$d\left(\frac{aX_{(1,D+)}^{MAX}}{X_{(1,D+)}^{MAX}+1} + \frac{bX_{(1,D-)}^{MAX}}{X_{(1,D-)}^{MAX}+1}\right) + g\left(\frac{aX_{(2,D+)}^{MAX}}{X_{(1,D+)}^{MAX}+1} + \frac{bX_{(2,D-)}^{MAX}}{X_{(1,D-)}^{MAX}+1}\right) - C$$

Proof of Proposition 5

If pay-per-use is the pricing strategy, $P_{(D+)} > 0, P_{(D-)} > 0, P_0 = 0$.

Solve the first derivatives of the optimal price:

$$X_{(1,D+)}^{MAX} = \frac{a_1}{P_{(D+)}} - 1 \tag{A1-14}$$

$$X_{(1,D-)}^{MAX} = \frac{b_1}{P_{(D-)}} - 1 \tag{A1-15}$$

$$X_{(2,D+)}^{MAX} = \frac{a_2}{P_{(D+)}} - 1 \tag{A1-16}$$

$$X_{(2,D-)}^{MAX} = \frac{b_2}{P_{(D-)}} - 1 \tag{A1-17}$$

The optimal profits of provider:

$$d\left(\frac{a_1X_{(i,D+)}^{MAX}}{X_{(i,D+)}^{MAX}+1} + \frac{b_1X_{(i,D-)}^{MAX}}{X_{(i,D-)}^{MAX}+1}\right) + g\left(a_2 - \frac{a_1}{X_{(i,D+)}^{MAX}+1} + b_2 - \frac{b_2}{X_{(i,D-)}^{MAX}+1}\right) - C$$

$$\max_{P_{(D+)},P_{(D-)}} d\left(P_{(D+)}X_{(1,D+)}^{MAX} + P_{(D-)}X_{(1,D-)}^{MAX}\right) + g\left(P_{(D+)}X_{(2,D+)}^{MAX} + P_{(D-)}X_{(2,D-)}^{MAX}\right) - C$$

$$= \max_{P_{(D+)},P_{(D-)}} d\left(a_1 - P_{(D+)} + b_1 - P_{(D-)}\right) + g\left(a_2 - P_{(D+)} + b_2 - P_{(D-)}\right)$$

According to Proposition 1, cloud provider needs to employ an appropriate pricing to optimize the potential revenues. Let's consider the following function first,

$$\max_{P_{(D+)}} d(P_{(D+)}X_{(1,D+)}^{MAX}) + g\left(P_{(D+)}X_{(2,D+)}^{MAX}\right) = \max_{P_{(D+)}} d\left(a_1 - P_{(D+)}\right) + g(a_2 - P_{(D+)})$$

In order to optimize the above function,

$$\frac{a_2}{X_{(i,D+)}^{MAX} + 1} \leq P_{(D+)} \leq \frac{a_1}{X_{(i,D+)}^{MAX} + 1}$$

Cloud provider is difficult to differentiate different types of customers, they need an identical pricing strategy to optimize their revenues. Meantime, in order to maximize the utility, the high-demand customers would like to optimize their demand as $X_{(i,D+)}^{MAX}$, and the low-demand customers' demand will increase because of the decreasing of market price of cloud services. Hence,

$$\max_{P_{(D+)}} d\left(P_{(D+)}X_{(1,D+)}^{MAX}\right) + g\left(P_{(D+)}X_{(2,D+)}^{MAX}\right)$$

$$= \max_{P_{(D+)}} d(P_{(D+)}X_{(1,D+)}^{MAX}) + g\left(a_2 - P_{(D+)}\right) = \max_{P_{(D+)}} ga_2 + (dX_{(1,D+)}^{MAX} - g)P_{(D+)}$$

When g$X_{(2,D+)}^{MAX}$ > d, the optimal price when the demand is maximal is $P_{(D+)} = \frac{a}{X_{(2,D+)}^{MAX}+1}$, otherwise, $P_{(D+)} = \frac{a}{X_{(1,D+)}^{MAX}+1}$.

When g$X_{(2,D-)}^{MAX}$ > d, the optimal price when the demand is minimal is $P_{(D-)} = \frac{b}{X_{(2,D-)}^{MAX}+1}$, otherwise, $P_{(D-)} = \frac{b}{X_{(1,D-)}^{MAX}+1}$.

Proposition 6.

If provider adopts with subscription, the optimal price is:

$a\log\left(X_{(2,D+)}^{MAX} + 1\right) + b \log X_{(2,D-)}^{MAX} + 1)$.

And the optimal profit is:

$$(d+g)\left(\mathrm{alog}\left(X_{(2,D+)}^{MAX}+1\right)+b\log(X_{(2,D-)}^{MAX}+1)\right)-C$$

Based on the results, $d\left(\frac{aX_{(1,D+)}^{MAX}}{X_{(1,D+)}^{MAX}+1}+\frac{bX_{(1,D-)}^{MAX}}{X_{(1,D-)}^{MAX}+1}\right)+g(\frac{aX_{(2,D+)}^{MAX}}{X_{(1,D+)}^{MAX}+1}+\frac{bX_{(2,D-)}^{MAX}}{X_{(1,D-)}^{MAX}+1})-C<$ $(d+g)\left(\mathrm{alog}\left(X_{(2,D+)}^{MAX}+1\right)+b\log(X_{(2,D-)}^{MAX}+1)\right)-C$.

Proof of Proposition 6

According to Proposition 2, cloud provider's asking price to the high-demand customer is:

$$a\log\left(X_{(i,D+)}^{MAX}+1\right)+b\log X_{(i,D-)}^{MAX}+1)$$

Cloud provider's asking price to the low-demand customer is:

$$a\log\left(X_{(i,D+)}^{MAX}+1\right)+b\log X_{(i,D-)}^{MAX}+1)$$

Since cloud provider cannot differentiate different types of customers, in order to optimize the revenues, the provider has to hold the high-demand customers, not to attract the low-demand customers. The asking price to both two types of customers should be

$$a\log\left(X_{(i,D+)}^{MAX}+1\right)+b\log X_{(i,D-)}^{MAX}+1)$$

Also, $a<\frac{d+g}{d}\ a$ and $b<\frac{d+g}{d}\ b$

Then, the optimize profits of provider is:

$$(d+g)\left[a\log\left(X_{(i,D+)}^{MAX}+1\right)+b\log X_{(i,D-)}^{MAX}+1)\right]-C$$

Because $X_{(i,D+)}^{MAX}\geq 0$ and $X_{(i,D+)}^{MAX}\geq 0$,

$$d\left(\frac{a\,X_{(i,D+)}^{MAX}}{X_{(i,D+)}^{MAX}+1}+\frac{b\,X_{(i,D-)}^{MAX}}{X_{(i,D-)}^{MAX}+1}\right)+g(a-\frac{a}{X_{(i,D+)}^{MAX}+1}$$

$$+b-\frac{b}{X_{(i,D+)}^{MAX}+1})-C<(d+g)\left[a\log\left(X_{(i,D+)}^{MAX}+1\right)+b\log X_{(i,D-)}^{MAX}+1)\right]-C$$

Hence, when $gX^{MAX}_{(2,D+)} > d$ and $gX^{MAX}_{(2,D-)} > d$, cloud providers will employ subscription as their cloud pricing strategy, because of the revenues from subscription is greater than that of pay-per-use. Therefore, cloud providers could obtain more revenues if they adopt with subscription instead of pay-per-use.

According to the mathematical proof of two categories of customers, homogeneous and heterogeneous customers, it is clearly indicating that subscription can generate more revenues than pay-per-use. In practice, mor and more cloud-relevant companies employ subscription instead of pay-per-use, to potentially reduce the marketing price of cloud resources and make more profits. Customers would like to seek any less expensive cloud resources of the same QoS through the pricing strategy of subscription as well. Therefore,

Corollary 1.

Subscription can help cloud service providers obtain more revenues. In other words, subscription is a better pricing mechanism than pay-per-use.

A.2 Dynamic Auction Design is Superb to Fixed Pricing Strategy

A.2.1 Monotonicity

Lemma 1: If one customer can win with bidding of B_i^t, he or she will continue to win for any ($B_i^{t'} > B_i^t$) bid.

Proof.

For a winning customer (i), his or her bidding density is $d^b = \frac{B_i^t}{\sqrt{Q_i^t}}$, and expenses is $P = \frac{B_{i-}^t}{\sqrt{Q_{i-}^t}} \times Q_i^t \times O_i^t$. O_i^t are other factors that impacting the value of cloud resources but not considered in the proposed mechanisms.

The winning customer (i) would involve in more auctions to purchase more cloud services. According to the payment function, if the customer wants to win again, the customer has two ways to do that: lifting the bid (B_i^t) or reducing sum of services (Q_i^t). Such as:

If

$$B_{i'}^t > B_i^t$$

Then

$$d^{b'} = \frac{B_{i'}^t}{\sqrt{Q_{i'}^t}} > d^b = \frac{B_i^t}{\sqrt{Q_i^t}} \tag{A2-1}$$

If

$$Q_{i'}^t < Q_i^t,$$

Then

$$d^{b'} = \frac{B_{i'}^t}{\sqrt{Q_{i'}^t}} > d^b = \frac{B_i^t}{\sqrt{Q_i^t}} \tag{A2-2}$$

Hence, the monotonicity can guarantee the winning customer obtain more cloud resources, if the customer doesn't have a limited budget constraint, because more cloud resources need more affordable investment, even though the customer may have chance to pay by the second highest price that is less than his or her own bid

A.2.2 A Double Auction is better than Subscription

Proof.

A provider j's utility (U_j) is,

$$U_j = B_{i^-}^t - P_0 \tag{A2-3}$$

A customer i's utility (U_i) is,

$$U_i = B_i^t - B_{i^-}^t \tag{A2-4}$$

The price of an economic efficiency mechanism (P_{EE}) is

$$P_{EE} = \frac{B_i^t + B_j^t}{2} \tag{A2-5}$$

The trading price of a double auction (P) is

$$P = \frac{B_x^{i^-}}{\sqrt{Q_x^{i^-}}} \tag{A2-6}$$

Proposition 7.

The utility of an economically efficient auction (U_{EE}) equals to the utility of a fixed price (U_F).

Proposition 8.

The utility of a double auction (U_i) is better than that of an economically efficient auction (U_{EE}).

Corollary 2.

Compared with subscription, a double auction generates more revenues.

For customer *i*, the utility of a double auction minus the utility of a fixed pricing is:

$$U_i - U_F \tag{A2-7}$$

Specifically,

$$U_i = B_i^t - B_{i^-}^t \tag{A2-8}$$

$$U_F = U_{EE} = B_i^t - P_{EE} \tag{A2-10}$$

$$U_i - U_F = \frac{B_i^t + B_j^t}{2} - B_{i^-}^t \tag{A2-11}$$

Based on the **Assumption**

$$(B_j^t \geq B_{i^-}^t)$$

And,

$$B_i^t \geq B_j^t,$$

Thus,

$$U_i - U_F \geq 0$$

Therefore, Corollary 2 is proved: a double auction generates more revenues than subscription.

VITA

Education

PhD | AUGUST 2015 - MAY 2020 | Old Dominion University (U.S.A.)

· Major: Business Analytics & Information Systems

MSc | AUGUST 2014 - DECEMBER 2005 | The University of Manchester (U.K.)

· Major: Economics and Statistics

BA | AUGUST 2000 - JULY 2004 | Jilin University (P.R. CHINA)

· Major: International Trade & Economics

Peer-Reviewed Journal Papers

· Lu, Y., Zheng, X. R., Li, L. & Xu, Li D. (2019). Pricing the cloud: a QoS-based auction approach. Enterprise Information Systems. 14(3), 334-351.

· Lu, Y. (2019). The blockchain: state-of-the-art and research challenges. Journal of Industrial Information Integration. Early Access. doi.org/10.1016/j.jii.2019.04.00.

· Lu, Y. (2019). Artificial intelligence: a survey on evolution, models, applications and the future trends. Journal of Management Analytics, 6(1), pp. 1-29.

· Lu, Y. & Xu, Li D. (2018). Internet of Things (IoT) cybersecurity research: a review of current research topics. IEEE Internet of Things Journal, 6(2), pp. 2103-2115.

· Lu, Y. (2018). Blockchain and the related issues: a review of current research topics. Journal of Management Analytics, 5(4), pp. 232-255.

· Lu, Y. (2017). Industry 4.0: a survey on technologies, applications and open research issues. Journal of Industrial Information Integration, 6, pp. 1-10.

· Chen, Y., Chen, H., Gorkhali, A., Lu, Y., Ma, Y., & Li, L. (2016). Big data analytics and big data science: a survey. Journal of Management Analytics, 3(1), pp. 1-42.

Book Chapter

· Lu, Yang. (2019). Deep Learning of Data Analytics in Healthcare. In Theory and Practice of Business Intelligence in Healthcare. Jiban, Khuntia and Ning, Xue. IGI Global, PA. Forthcoming in October 2019.

Work Experience

Visiting Assistant Professor (Full-Time) | Department of Supply Chain & Information System, School of Business, College of Charleston | August 2018 – May 2020

Membership

· Association of Information Systems (AIS)

· Institute of Electrical and Electronics Engineers (IEEE)

· Decision Sciences Institute (DSI)

· Institute for Operations Research and the Management Sciences (INFORMS)