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Pricing Cloud Compute Commodities: A Novel Financial Economic Model

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Abstract— **In this study, we design, develop, and simulate a cloud resources pricing model that satisfies two important constraints: the dynamic ability of the model to provide a high satisfaction guarantee measured as Quality of Service (QoS) - from users perspectives, profitability constraints - from the cloud service providers perspectives We employ financial option theory and treat the cloud resources as underlying assets to capture the realistic value of the cloud compute commodities (C^3). We then price the cloud resources using our model. We discuss the results for four different metrics that we introduce to guarantee the quality of service and price as follows: (a) Moore's law based depreciation of asset values;(b) new technology based volatility measures in capturing price changes; (c) a new financial option pricing based model combining the above two concepts; and (d) the effect of age of resources and depreciation of cloud resource on QoS. We show that the cloud parameters can be mapped to financial economic model and we discuss the results of cloud compute commodity pricing for various parameters, such as the age of the resource, quality of service, and contract period.**

I. INTRODUCTION AND MOTIVATION

The consumption of information technology resources by general public and businesses has been increasing tremendously in the recent past. Convergence of Grid, Utility computing and SaaS (Software as a Service) have led the development of service oriented computing presented as Cloud. External deployment of compute power, storage or applications as services on need basis has been the prime motivation behind this development.

Cloud Computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centers that provide those services [3], [4]. Core feature of Cloud computing is provision of IT infrastructure and applications as a service in a scalable way. From the perspective of providers, the major Cloud component is the data center. Foster et al. [8] define Cloud as "a large-scale distributed computing paradigm that is driven by economies of scale, in which a pool of abstracted, virtualized, dynamically-scalable, managed computing power, storage, platforms, and services are delivered on demand to external customers over the Internet". Another definition by Buyya [6] suggests "Cloud is a market-oriented distributed computing system consisting of a collection of inter-connected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resources based on service-level agreements (SLA) established through negotiation between the service provider and consumers".

All definitions illustrate that Cloud Computing is a phenomenon that comprises a number of aspects and is related to a new paradigm of IT (hardware and applications) delivery and deployment.

Governments, research institutes, and industry leaders are rushing to adopt Cloud computing to solve their ever increasing computing and storage problems arising in the Internet age. There are three main factors contributing to the surge and interests in Cloud computing: (1) decrease in hardware cost, increase in computing power and storage capacity, advent of multi-core architecture and modern supercomputers consisting of hundreds of thousands of cores; (2) the exponentially growing data size in scientific instrumentation/simulation and Internet publishing and archiving; and (3) the wide-spread adoption of Services Computing and Web 2.0 applications.

The research work in Cloud has spanned into many directions. Many research efforts have focused on resource virtualization, data migration, monitoring and management and security (see for example [7]). While all these research works strive to provide seamless service to clients at high quality of service, the fee for providing these services has been left to the providers themselves. While for an occasional user this cost may not be a big burden, businesses that avail of the Cloud services on a continuous basis at a certain fee might be incurring more expense in using these services than they own these infrastructure. This is due to the fact that setting up a required service in-house for the businesses is not difficult and the utility/cost ratio would possibly upset the utility/fee ratio, if the fee being paid by the business for Cloud usage is unchecked.

Cloud resources (we call them Cloud Compute Commodities (C^3)) pricing is a challenging task when viewed as a generic pricing problem. In a Cloud system for example, the resources exist as non-storable commodities and are distributed across wide geographical regions.

To price the C^3, the presence of flexibilities grant the

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users an obligation-free C^3 usage except for the fee for usage. If the users' computing needs change in the future, the user may modify the requests as against the anticipated usage. Therefore, to price Cloud resources in the presence of the flexibilities, we treat the C^3 as assets and employ three steps: (a) we model the C^3 pricing function as an option pricing problem (b) we model the Cloud resources price using a continuous time approach; and (c) we address uncertainty constraints inherent in achieving required quality of service (QoS) through the use of technological and economic principles. We achieve this objective by considering the profitability for the provider and cost saving for the user. In other words, we price the C^3 with provider's profit in mind and show that this level of pricing is still attractive and low cost to the users. We achieve relative equilibrium due to the emphasis on the Cloud provider's profit. By relative equilibrium we mean that both the provider and user in a contract benefit from our pricing strategy.

In general, the C^3 are provided as reserved, on-demand and spot instances. The spot instances is a new type of instance introduced by Amazon in late 2009 [2]. The current study concerns pricing Cloud resources without any reference to the kind of service provided (reserved, on-demand or spot instances). Therefore, in this study, we do not consider the "bidding" concept. However, we show that without such bidding the users will still be paying prices that are beneficial for them while at the same time the providers can make profit for their investment on Cloud resources.

Rest of the paper is organized as follows: in the next section I-A, we describe the basics of financial option in simple terms followed by related work in section II where we focus on work related to pricing of Cloud resources. In section III, we discuss the model formulation, where we introduce a continuous time option pricing model, the Black-Scholes-Merton model. We then introduce how the Moore‘s law is used in our study to reflect the price change resulting from the technological evolution that follows Moore's law. Most of the new concepts introduced in this study such as the Compounded Moore‘s law, and mapping of Cloud parameters to Black-Scholes-Merton model are discussed in this section. In section IV, we describe our pricing algorithm, experiments and results. We conclude our study in section V.

A. Financial Options

Options are derivative securities because their value is a derived function from the price of some underlying asset upon which the option is written. They are also risky securities because the price of their underlying asset at any future time may not be predicted with certainty. A financial option is defined (see, for example [9]) as the right to buy or to sell an underlying asset that is traded in an exchange for an agreed-upon sum (strike price or exercise price). The right to buy or sell an option may expire if the right is not exercised on or before a specific date (maturity date for the contract) and the option buyer forfeits the premium paid at the beginning of the contract. The exercise price *(strike price)* specified in an option contract is the stated price at which the asset can be bought or sold at a future date. A *call option* grants the holder the right to purchase an underlying asset at the specified strike price. On the other hand, a *put option* grants the holder the right to sell an underlying asset at the specified strike price. An *American option* can be exercised at any time during the life of the option contract while a *European option* can only be exercised at maturity of the contract. Basically there are five parameters needed to compute option values: asset price, strike price, contract period, risk-free interest rate and volatility of the asset price.

In this paper, we focus on the valuation of C^3, with specific emphasis on the provision of a satisfaction guarantee in terms of the QoS requirements at low cost to the clients while ensuring the Cloud service provider also profits for the services. The contributions of this paper are three fold: (1) mapping Cloud parameters to financial option market; (2) use of finance option based pricing of Cloud resources; (3) Applying Moore's law based Cloud resource price evolution; and (4) design of an algorithm that combines these concepts for pricing Cloud resources.

II. RELATED WORK

In this section, we discuss recent works relevant to the pricing issues in Cloud. Note that none of the related works in the literature use financial option concepts to Cloud resources. In [16], the author analyzes the true cost of leasing a cpu for an hour against acquiring and owning the same cpu. This study concludes that financial option based pricing would be an appropriate technique for Cloud resource pricing.

Patel and Shah [14] explore the cost incurred by data centers. This study focuses on three major issues: space, power and cooling on cost model. They provide a step by step analysis of the cost for each of the three issues and sum these costs to obtain a comprehensive cost of running a data center. The authors of this study do not go any further in finding the cost of Cloud resources meant to be sold as a service.

A recent study on the economy of spot instances by Wee [17] suggest that additional cost savings to the businesses for moving the workload from off-peak periods to spot instances is not large. This cost savings is achievable under certain ideal conditions, for example, on scheduling for dispatching tasks. Their study looked at one year of Amazon's spot instance price data to come to this conclusion.

Another recent work [15] explored ways of increasing the profit for IaaS providers by increasing the resource utilization. The authors studied this problem for a Cloud provider within a "Cloud federation" and they suggested several policies to increase utilization based on the resource prices at other providers within the federation. Fundamentally, this study focuses on increasing the profit for a provider through higher utilization of the resources.

In order to understand the price fluctuation of Amazon spot instances, a recent work [10] explored to fit a statistical model to the existing prices. Using the proposed model, the authors have done a comprehensive analysis of spot instances based on one year price history in four data centers of Amazon's EC2. The authors showed that the statistical model they have proposed fits well with these data series and claim that they would be able to model the dynamics of spot price. This model could be used to predict the spot instance prices of Amazon EC2 instances and hence close to the pricing of resources that we explore in this study.

All these studies have focused on investigating the existing prices or how to derive cost savings for the users based on current prices mostly for spot instances. To our best knowledge, devising a quantitative approach for the price of Cloud resources has not been the subject of investigation. There are few studies in the recent past that explored use of financial option concept for pricing grid resources [1] and pricing transmission rights in power systems [11]. These studies consider financial option theory in its original form, which cannot be directly extended to pricing Cloud resources. This is because of the price fluctuation in Cloud instances as well as fluctuation in their availability. We employ other known concepts such as Moore's law (for the quality of the resources in Cloud) and combine it with interest rate formula to price Cloud resources for current market conditions. Hence, this work is unique in many fronts for the Cloud services.

In this study, we design, develop, and simulate a cloud resources pricing algorithm that considers many of the market constraints. We employ hitherto unattempted financial option theory and treat the cloud resources as assets to capture the realistic value of the Cloud compute commodities (C^3). We then price the cloud resources by solving the finance model. We discuss the results for four different metrics: (a) Moore's law based depreciation of asset values;(b) new technology based volatility measures in capturing price changes; (c) A new financial option pricing based model combining the above two parameters; and (d) the effect of age of resources and depreciation of cloud resource on QoS. We show that the cloud parameters can be mapped to financial economic model and we discuss the results on cloud compute commodity pricing for various parameters, such as the age of the resource, quality of service, and contract period.

III. MODEL FORMULATION AND METHODOLOGY

In this section we explain Black-Scholes-Merton (BSM) model and Moore's law,. These two form the basis of our computational model derived as compounded Moore's law. Then we explain the input parameters for cloud pricing and mapping of these parameters to standard BSM model.

A. Black-Scholes-Merton Model

Fisher Black and Myron Scholes [5] and Robert Merton [12] devised a model for option pricing in 1973 which was formulated as a set of partial differential equations. This model revolutionized the option market and received Nobel prize for Economics in 1997. This model can be used to obtain a closed form solution for European call and European put option. That is, if we know the five input parameters for options as described later in this section, we can compute the option value using this model.

Approximate solutions for various options like complex chooser, time switch options etc. are based on the BSM model. In this study we use plain options without any complications. It is possible in future to look into properties of complex options to map to C^3 and hence to price Cloud resources for complicated contracts.

The classical BSM formula for a call option is given by [9].

$$C(S,t) = N(d_1) \times S - N(d_2) \times K \times e^{-r(T-t)} \quad (1)$$

where,

$$d_1 = \frac{\ln(S/K) + (r + \sigma^2/2)(T-t)}{\sigma\sqrt{(T-t)}}, and \quad (2)$$

$$d_2 = d_1 - \sigma\sqrt{(T-t)} \quad (3)$$

The Black-Scholes formula for put option is

$$P(S,t) = N(-d_2) \times K \times e^{-r(T-t)} - N(-d_1) \times S \quad (4)$$

In these equations, S is the underlying asset price, K is the strike price in the contract, r is the interest rate, σ is volatility, t is the time and T is the maturity date. $N(d)$ represents the normal distribution function on d.

Although BSM model has been used for option pricing, it has some drawbacks. First, the closed-form solutions are applicable only for European call and put options. Second, this model assumes constant market volatility (σ) which does not reflect the real market scenario. Initially, for this study we want to test the feasibility of our algorithm on this simple model before expanding in the future.

B. Moore's Law

Gordon E. Moore [13] in 1965 stated that the number of transistors that can be placed on a circuit will double roughly every eighteen months. This statement has been observed to be true so far and hence attained the status of a *law*. This law holds true for processing power, memory etc. This law can be presented as:

$$ProcessingPower_{t=T} = ProcessingPower_{t=0} \times 2^{T/2} \quad (5)$$

We can use Moore's law to estimate the improvements in hardware design, but this law cannot be used directly to estimate the price of new hardware because in pricing there are some other factors such as rate of inflation, to be taken into account. We use the compound interest formula along with the Moore's law to use it for Cloud resource pricing. We call this *Compounded-Moore's* Law.

1) Compound interest formula: The $FutureValue$ of an asset can be evaluated using the $PresentValue$, the rate of interest (r) and the number of years (n) using this formula

$$FutureValue = PresentValue \times (1+r)^n \quad (6)$$

The PresentValue can be equated to the initial investment by the provider in building a Cloud data center and the FutureValue is the initial investment's worth at the end of the contract period. That is to say that the "interest rate" is the rate of depreciation of the investment on infrastructure.

The Moore's law covers the technical aspect and compound interest covers the financial aspect of the hardware. For pricing C^3, depreciation of the existing infrastructure, inflation, and technological evolution based on Moore's law all have to be considered together. For this purpose, we introduce a new formula presented below.

2) Compounded-Moore's law: Combining the equations (5) and (6) we get the following equation for Compounded-Moore's law.

$$XResourceVal_{t=T} = XResourceVal_{t=0} \times (1+r)^{T/2} \quad (7)$$

This equation calculates the depreciation of Resource X based on Moore's law. However, in conjunction with compound interest formula presented above, the value of the resource X is computed indirectly through this equation as well. That is, this equation now covers the technical and financial aspect of the resource.

C. Cloud parameters

There are five parameters pertinent to pricing Cloud resources.

1) $Initial\_investment$: This is the amount of money a Cloud service provider will spend per year. Suppose that the service provider wants to buy a resource X each year. According to the Compounded-Moore's law, for a given investment duration the provider will reap more processing power at a constant price. Also, the service provider will pay less amount to buy the same resource X next year and even lesser in the subsequent years.
2) $Contract\_time$: It is the time for which the client wants to lease the resources of the Cloud service provider.
3) $Rate\_of\_depreciation$: It is the rate at which the hardware of service provider is expected to lose its financial value. This could be the result of wear and tear or due to the advent of some new technology. In both the cases the clients would want to switch to the newer and better technology. The pricing policies of service provider should be such that they make profits on their initial investments before the clients no longer want to lease those resources.
4) $Quality\_of\_service$: This is the quality assurance from service provider to the client. This could include the turnaround time, accuracy of results, data privacy and contingency plans .
5) $Age\_of\_resources$: It represents the age of a particular resource the service provider is leasing to the client.

D. Mapping Cloud Parameters to BSM Model

As discussed before, BSM model has five input parameters S, K, r, t and σ. The mapping of these parameters to Cloud parameters is shown in the algorithm below. $Total\_investment$ is the total money that the service provider will spend during the lifetime of a contract and its value can be calculated using Compound-Moore's equation with $Initial\_investment$ as one of the input parameter. $Strike\_estimate$ is the equivalent of K of BSM model, evaluated using Compounded-Moore's formula with $Contract\_time$ and $Rate\_of\_depreciation$ an input parameters. Similarly $Volatility\_estimate$ is the equivalent of σ of BSM model with $Age\_of\_resources$ and $Rate\_of\_depreciation$ as input parameters.

Algorithm 1 Pricing Cloud resources

```
Get the input Cloud parameters
$Total\_investment$ = Compounded-Moore (Contract_time, Initial_investment).
$Strike\_estimate$ = Compounded-Moore(Contract_time, Rate_of_depreciation).
$Volatility\_estimate$ = Compounded-Moore(Age_of_resources , Rate_of_depreciation).
Map Cloud parameters to Black-Scholes-Merton equation parameters as follows
    $S$ ⇐Total_investment
    $K$ ⇐Strike_estimate
    $r$ ⇐Quality_of_service
    $t$ ⇐Contract_time
    $\sigma$ ⇐Volatility_estimate
Use standard Black-Scholes-Merton equation to price the Cloud resource.
```

IV. EXPERIMENTS AND RESULTS

We consider five different scenarios of pricing Cloud resources. But before explaining these scenarios, we show one set of simulation and evaluate the savings the client will make in leasing the resources instead of buying and owning those resources. The table I shows the results obtained from the BSM model for a typical parameter setting in an experiment. The experiment was repeated for different initial values of the parameters to analyze the effect of individual parameter on the pricing results.

We can divide the pricing process in two main steps

1) Use of Compounded-Moore's law: The five Cloud parameters are: Initial investment, contract time, rate of depreciation, quality of service and age of resource. Using these five input parameters with Compound-Moore's law we calculate the setting up cost for the service provider, that is, 2.14 cents/hour in the

TABLE I

A TYPICAL RESULT FROM OPTION CONTRACT.

Parameter	Value
Initial Investment ($/year)	300
Contract period (years)	3
Rate of depreciation (%)	10
Quality of Service	1.0
Age of resources (years)	2
Cost to service provider (cents/hour)	2.14
Cost to client (cents/hour)	1.65

example presented in table I. This is the maximum amount the service provider is spending to buy and set up the hardware resources. In other words, this is the *upper bound* on the Cloud resource price the provider would like to charge a client for resources to recover the investment over the contract period. The cost of maintenance (including power, real estate and personnel etc.) is not considered in this study. However, the revenue generated by providing service to many clients (at a low cost to them) from a given virtualized resource is assumed to compensate the maintenance cost to the provider. This is one of the limitations of the current study and we are currently exploring the effect of maintenance cost on the resource price and will be discussed in a later publication. We can expect that adding the cost of maintenance in the first step of price evaluation would bring profits to the provider sooner.

2) Use of BSM model: Treating the Cloud resources as assets, we use BSM model to find the optimal price the service provider should charge the clients to recover its initial investment. With the use of BSM model we get a price of 1.65 cents/hour; this implies that the service provider should charge the client at least 1.65 cents/hour in order to recover the initial investment. In other words this is the *lower bound* on the Cloud resource price.

The fee the service provider will charge the clients has to be between these upper and lower bounds based on negotiations and market conditions. It can be seen that if the resource is priced between these two bounds it is beneficial to both clients and service provider. As long as price of leased resource is more than 1.65 cents/hour the service provider will recover the initial investment (and under certain circumstances provider can make profit on top of that). Similarly as long as the price of leased resource is less than 2.14 cents/hour, the clients are benefitting the low cost of the resources as well; for, if the clients had to buy all the resources instead of leasing, they would be incurring expenses at 2.14 cents/hour for the similar resources. Therefore, by leasing the resource from the Cloud service provider and paying less than 2.14 cents/hour, the client is satisfied as well.

Another point to note here is that if the client had to purchase the resource, the value of the client's investment at risk is 100%. However, by leasing the resources from a Cloud service provider the client has none of the investment is at risk of losing value. That is, the value at risk for clients is 0%. The case explained above involves one client and one service provider; however in reality a single service provider will have many clients. With virtualization of the resources, the service provider can cater to the needs of many clients from a given physical resource, thus generating more revenue on the initial investment of 2.14 cents/hour and hence make profit.

Therefore, it can be understood that client and the service provider can have a symbiotic relationship. Experiments results presented in the next section show the influence of various Cloud parameters on the Cloud resources.

A. *Effect of initial investment on Cloud resource price*

The effect of increasing initial investment on Cloud resource can be seen in figure IV-A.

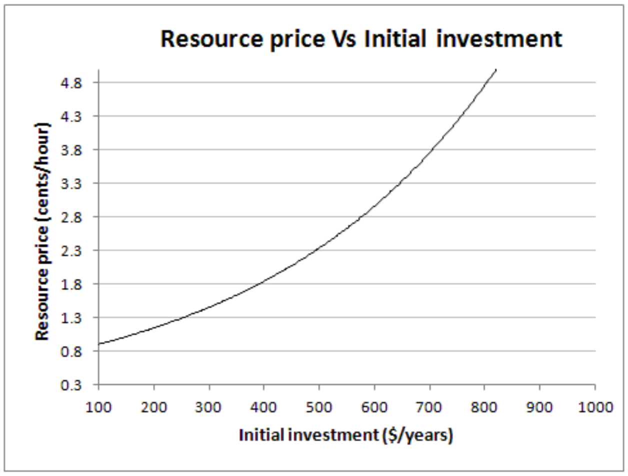

Fig. 1. Effect of initial investment on the resource price

We see that the resource price (asking price) increase is proportional to the initial investment of the service provider. This proportionality is due to the fact that the contract period is kept constant. Our algorithm allows us to vary the contract time between a single client and provider. Handling multiple clients with varying contract periods becomes a problem of resource allocation first. Once the tasks are assigned to the appropriate resources, we can price the resources. We have not considered the task assignment problem in this study. Also, note that the experimental result in this figure IV-A is for a slightly different parameter setting than table I.

B. *Effect of contract time on Cloud resource price*

The effect of contract time on the Cloud resource price can be seen in the figure IV-B.

It can be seen that its beneficial for client to lease the Cloud resource for a longer time; the prices decrease as the contract time increases. That is, longer running tasks could benefit from the use of Cloud resources to a larger extent than

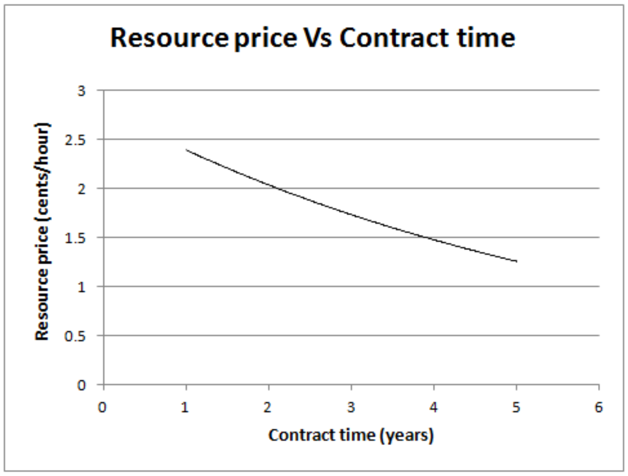

Fig. 2. Effect of contract period on the resource price

the smaller jobs. This is due to two reasons: (1) the resource price variation could average out over a long period of time; and (2) smaller jobs may get executed at a time when the resource price is at its peak (between 2.14 and 1.65 cents per hour, for example). Note that in the current set up, as long as the price is between the lower and upper bounds, both Cloud provider and client are getting benefitted.

C. Effect of rate of depreciation on Cloud resource price

The expected rate of depreciation of the hardware installed by the service provider is very critical to price the Cloud resource. As explained earlier, if the rate of depreciation is high the service provider would like to recover its investment before the hardware becomes obsolete, which in turn would increase the price of Cloud resource. This can be seen in figure IV-C.

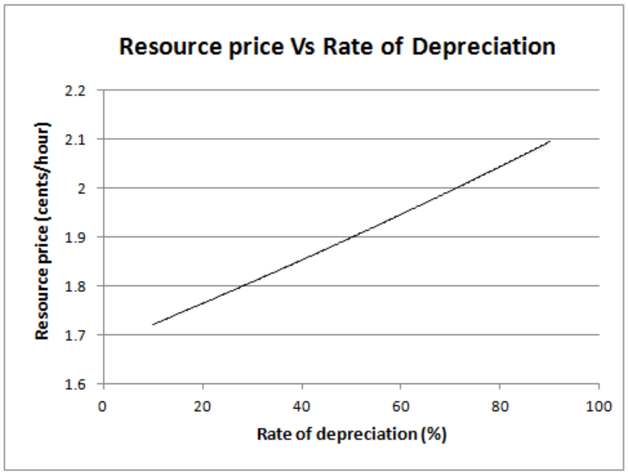

Fig. 3. Effect of rate of depreciation on the resource price

D. Effect of quality of service on Cloud resource price

Higher the quality of service the client demands, more is the asking price from the service provider as evident from the figure IV-D. A price range presented earlier is still valid for this discussion. That is, the upper bound price would correspond to the highest QoS. In other words, the compounded-Moore's law based pricng and BSM model based pricing form boundaries of the price range for which the QoS varies proportionately.

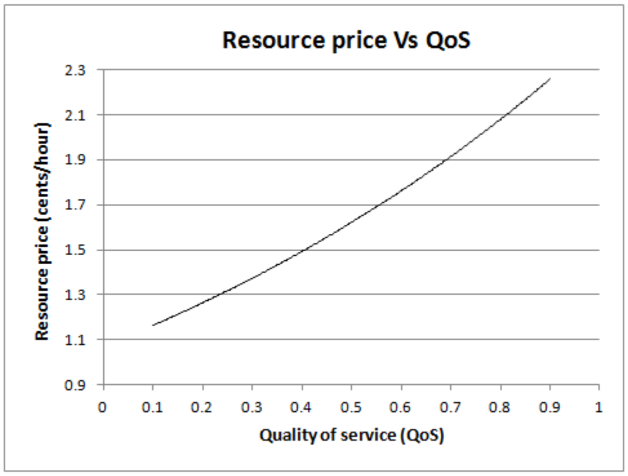

Fig. 4. Effect of quality of service on the resource price

E. Effect of age of resource on Cloud resource price

The age of resource had no impact on the Cloud resource price as shown in the figure IV-E. This is because the quality of service is kept constant as we varied the age of resources in our simulations. This implies that the client is just concerned about the quality of work rather than the hardware used to accomplish the task. The Cloud service provider might incur more expenses managing aged resources. However, the client is completely immune to it.

F. Limitations of this study

For a given physical resource, we assume that the initial investment would be same for client and the service provider alike; however, in real market this is rarely the case. The Cloud service provider building a data center would incur proportionately would incur less cost due to bulk procurement of resources. For example, a client might have to spend \$100 for a single processor, while a service provider might be spending \$700 for ten such processors, a 30% cost saving. The second assumption is that the cost of maintenance of a particular resource would be similar or same order for service provider and the client. Going by the same justification as explained above, the cost of maintenance would be less for a service provider. We have not included these two factors (cost saving in procuring physical resources and cost of maintenance) in our model,

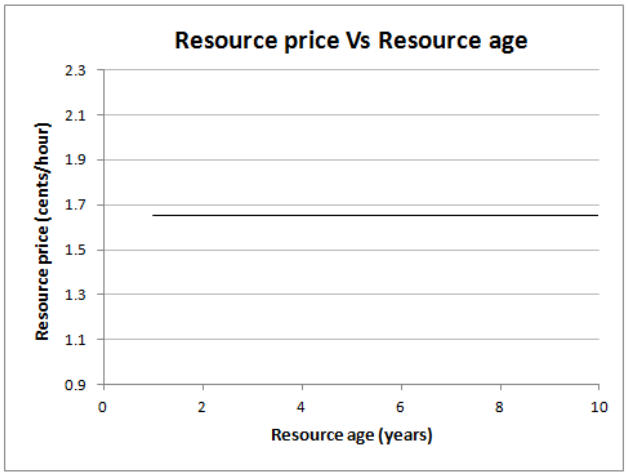

Fig. 5. Effect of age of the resource on the resource price

and based on the arguments following table I, we believe that these would further encourage a client to lease the resources from a service provider rather than buying the resources. Therefore, it can be understood that client and the service provider can have a symbiotic relationship.

V. CONCLUSIONS

In this study, we design, develop, and simulate a Cloud resources pricing model. We employ financial option theory and treat the Cloud resources as real assets to capture the realistic value of the cloud compute commodities(c^3). We then price the Cloud resources by solving the finance model. The finance model can be interpreted to give a lower bound on the prices. The upper bound can be found using the compounded-Moore's law that takes into account the metrics (initial investment, rate of depreciation, age of resource) that we have introduced in this study. The compounded-Moore's law in its current simple form can handle pricing of resources at a required QoS. This study opens up many further studies for more realistic Cloud pricing problem that would include provider's cost of maintenance and other costs.

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