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Spot pricing in the Cloud ecosystem: A comparative investigation

Zheng Li [a], He Zhang [b,*], Liam O'Brien [c], Shu Jiang [b], You Zhou [b], Maria Kihl [a], Rajiv Ranjan [d]

[a] Department of Electrical and Information Technology, Lund University, Lund, Sweden
[b] State Key Laboratory of Novel Software Technology, Software Institute, Nanjing University, Jiangsu, China
[c] Geoscience Australia, Canberra, ACT, Australia
[d] School of Computing Science, Newcastle University, Newcastle, United Kingdom

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ABSTRACT

Background: Spot pricing is considered as a significant supplement for building a full-fledged market economy for the Cloud ecosystem. However, it seems that both providers and consumers are still hesitating to enter the Cloud spot market. The relevant academic community also has conflicting opinions about Cloud spot pricing in terms of revenue generation.

Aim: This work aims to systematically identify, assess, synthesize and report the published evidence in favor of or against spot-price scheme compared with fixed-price scheme of Cloud computing, so as to help relieve the aforementioned conflict.

Method: We employed the systematic literature review (SLR) method to collect and investigate the empirical studies of Cloud spot pricing indexed by major electronic libraries.

Results: This SLR identified 61 primary studies that either delivered discussions or conducted experiments to perform comparison between spot pricing and fixed pricing in the Cloud domain. The reported benefits and limitations were summarized to facilitate cost-benefit analysis of being a Cloud spot pricing player, while four types of theories were distinguished to help both researchers and practitioners better understand the Cloud spot market.

Conclusions: This SLR shows that the academic community strongly advocates the emerging Cloud spot market. Although there is still a lack of practical and easily deployable market-driven mechanisms, the overall findings of our work indicate that spot pricing plays a promising role in the sustainability of Cloud resource exploitation.

1. Introduction

Cloud computing has been increasingly acknowledged in industry not only for benefiting Cloud providers by creating more business opportunities, but also for relieving Cloud consumers of purchasing, installing, and maintaining local compute resources. To guarantee a successful and sustainable Cloud ecosystem, suitable pricing techniques must be developed and implemented (Weinhardt et al., 2009). When it comes to trading Cloud resources, fixed pricing is the dominant strategy in the Cloud market nowadays [XL13] (Al-Roomi et al., 2013).[1] In particular, the most common pricing scheme (namely *pay as you go*) is for on-demand Cloud services, where employing a unit of service is charged a fixed price per unit of time [AKK12]. Given the normally unpredictable and stochastic demand, however, there would always be unused resources in the virtually infinite compute capacity of the Cloud. To help further and better utilize the idle compute resources, a promising approach is to provide spot resources at a reduced price so as to attract more demands with toleration of service delay and interruptions [WQH+13]. In fact, a commercial spot market has been established when a spot instance service was launched by Amazon in December 2009 [SYG13]. Given the de facto spot price traces that are generally far below the on-demand prices, spot pricing is claimed to be the most cost-effective scheme among the existing options for Cloud consumers. More importantly, Amazon's offering of spot service has been regarded as the first step toward a full-fledged market economy for Cloud computing [AKK12].

Unfortunately, there seems to be a lack of confidence in becoming Cloud spot pricing players in industry. Both providers and consumers are still hesitating to enter the Cloud spot market. For instance, the overwhelming majority of the existing Cloud providers have not

* Corresponding author. Tel.: +86 25 83621189.
E-mail address: dr.hezhang@gmail.com, hezhang@nju.edu.cn (H. Zhang).

[1] We use two types of bibliography formats: the alphanumeric format denotes the Cloud service evaluation studies (primary studies) of the SLR, while the name-date format (present in the "References" section) refers to the other references for this article.

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employed the spot pricing scheme yet [ZG11], and the only currently available provider Amazon is still using contests to encourage more spot applications (Amazon, 2015b). The possible reasons for not joining the Cloud spot market could exist behind the limitations of spot pricing. Unlike the static and straightforward pricing schemes of on-demand and reserved Cloud services, the market-driven mechanism for pricing spot service would be complicated for both implementation and understanding. Moreover, since the overall supply and demand of spot resources are both uncertain during runtime, spot service consumers would have to suffer from the irregular fluctuations in service price and availability.

Meanwhile, there are also conflicting opinions in the relevant academic community. As mentioned previously, offering spot resources has been viewed as an effective approach to attracting more consumers, fully utilizing the Cloud resources, and generating more revenue [WQH+13]. Nevertheless, some theoretical analysis and simulation argued that directly using fixed prices would bring higher expected revenues for providers than employing a hybrid (fixed + spot) pricing scheme [AKK12]. It is difficult to give a quick judgment on this even if referring to Amazon's spot service as a concrete example, because the public can obtain little information except the short-term history of spot prices.

To help alleviate the conflict in such a background and understand whether or not it is reasonable to employ spot pricing for Cloud computing, we conducted a systematic literature review (SLR) (Kitchenham and Charters, 2007) in order to rigorously identify, assess, and synthesize empirical evidence in favor of or against Cloud spot pricing. In addition to analyzing the benefits and limitations of spot pricing, we also distinguished between different theories (Gregor, 2006) proposed to describe/predict prices or explain/prescribe pricing mechanisms in the Cloud spot market. Furthermore, we particularly investigated the fault-tolerance techniques developed to address the limitations of Cloud spot pricing.

Accordingly, the contributions of this work are mainly threefold. Firstly, the systematically summarized discussions and empirical evidence can help both Cloud providers and consumers gain a quick impression of the pros and cons of the spot pricing scheme. Moreover, this report is further able to act as a checklist to facilitate cost-benefit analysis of offering/employing spot services. Secondly, the four types of relevant theories can help both researchers and practitioners better understand the Cloud spot market. In practice, the price prediction techniques involved in the predictive theories would be particularly valuable for Cloud consumers to make proper biddings, while the various prescriptive theories would be able to inspire Cloud providers to develop/improve their spot pricing mechanisms. In academia, researchers may refer to the existing theories to cross check and review new studies on Cloud spot pricing. Thirdly, the collected fault-tolerance techniques aim to give Cloud consumers an overview about how to achieve tradeoffs between economic benefits and service availability.

The remainder of this paper is organized as follows. Section 2 briefly introduces the related work on Cloud spot pricing. Section 3 specifies the SLR method and logistics in our study. Section 4 reports an overview of the reviewed studies, while Section 5 presents our main findings from this SLR by answering the predefined research questions. A set of possible threats to the validity of this study are highlighted in Section 6. Conclusions and some future work are discussed in Section 7.

2. Related work

It has been recognized that adequate pricing techniques would play a key role in the success of Cloud computing in practice (Weinhardt et al., 2009). In the de facto Cloud market, different providers have employed different strategies to attract consumers and sell their Cloud services. In general, there are three typical pricing schemes mainly based on Amazon's specification (Amazon, 2015a), as listed below.

- **On-demand service pricing scheme**: Cloud consumers pay a fixed cost per service unit on an hourly basis without upfront fee and long-term commitment. An analogy of this pricing scheme can be paying per view from a video on demand (VOD) service through the Internet.
- **Reserved service pricing scheme**: Cloud consumers pay an upfront fixed fee to ensure discounted hourly pricing for a long-term commitment of service availability (e.g., 1 year, 3 years). An analogy of this pricing scheme can be signing a two-year subscription of mobile service to receive cheaper data plans with a free phone.
- **Spot service pricing scheme**: Cloud consumers bid on spare resources and employ them whenever the bid exceeds the current spot price, while the employed service will be interrupted when the spot price exceeds the current bid. An analogy of this pricing scheme can be the dynamic pricing in the electricity distribution industry.

Although the fixed pricing schemes are dominant approaches to trading Cloud resources nowadays (Weinhardt et al., 2009), spot pricing has been broadly agreed as a significant supplement for building a full-fledged market economy for the Cloud ecosystem [AKK12]. In fact, a wide consensus on efficient management of resources in our society is to avoid fixed pricing (Meir and Rosenschein, 2013). As such, spot pricing (also dynamic pricing) methods have been increasingly developed and adopted in various industries ranging from airlines to electric utilities (Desiraju and Shugan, 2006; Elmaghraby and Keskinocak, 2003). Nevertheless, considering the unique characteristics of Cloud computing like location independence, resource virtualization and rapid elasticity, it could be improper to directly confirm the benefits of Cloud spot pricing by analogy with that in other industries.

As a matter of fact, the recent intensive investigations into Cloud spot pricing (e.g., [JTB13,LLLZ13,ZG13]) have delivered diverse and even contradictory statements. In particular, the simulation in the study [AKK12] indicates that spot pricing scheme would generate lower expected revenue for Cloud providers, which conflicts with the aforementioned consensus in most cases. Several survey studies tried to give an overview of, and comparison between different Cloud pricing schemes (Al-Roomi et al., 2013; Samimi and Patel, 2011)[KKP15,dSdMSNG+12]. Unfortunately, none of them emphasized empirical evidence for the comparison between spot pricing and fixed pricing. Furthermore, these survey studies delivered confusing terminology and classifications to readers. For example, various theoretical and mathematical models were directly treated as different Cloud pricing schemes, whereas those models are essentially for explaining or implementing the spot pricing scheme.

Our work focuses on the empirical evidence of spot pricing in the Cloud industry. In addition to outlining an overview of the benefits and limitations of Cloud spot pricing, we also report a theory-based classification of the relevant studies for researchers' and practitioners' reference.

3. Review method

The comprehensive guidelines for performing SLR have been specified by Kitchenham and Charters (2007). Here we adapted the guidelines to this work and followed a three-stage review procedure, as illustrated in Fig. 1.

In particular, given the existing experiences of SLR (Babar and Zhang, 2009; Li et al., 2013), we also emphasized the pilot review during Planning Review stage. In fact, initially reading some relevant studies would be crucial for understanding the domain knowledge and justifying the SLR work, which essentially brought the research questions. Furthermore, during the development of the review protocol, the pilot review can help gradually improve search strategy,