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Cloud Goliath Versus a Federation of Cloud Davids: Survey of Economic Theories on Cloud Federation

Kibae Kim, Songhee Kang, Jörn Altmann

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서 울 대 학 교
공 과 대 학, 기술경영경제정책 대학원과정
151-742 서울시 관악구 관악로 599

Technology Management, Economics, and Policy Program
College of Engineering, Seoul National University
599 Gwanak-Ro, Gwanak-Gu, Seoul 151-742, South-Korea
Phone: ++82-2-880-9140, Fax: ++82-2-880-8389

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Jörn Altmann, Editor

Office: 37-305
Technology Management, Economics, and Policy Program
College of Engineering
Seoul National University
599 Gwanak-Ro, Gwanak-Gu
Seoul 151-742
South-Korea

Phone: +82-70-7678-6676
Fax: +1-501-641-5384
E-mail: jorn.altmann@acm.org

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Survey of Economic Theories on Cloud Federation

Kibae Kim, Songhee Kang, Jörn Altmann

Technology Management, Economics, and Policy Program
College of Engineering
Seoul National University
Seoul, South-Korea
kibaejjang@gmail.com, soyedda@gmail.com, jorn.altmann@acm.org

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Abstract: Cloud computing, which can be described as a technology for provisioning computing infrastructure as a service, runtime platform as a service, and software as a service, is considered as a keystone for innovation in the IT area. However, a limiting factor to innovation through cloud computing could be the economies of scale and network externalities that give more benefits to larger cloud providers. Due to the economies of scale and network externalities in an oligopolistic environment, a giant cloud provider can offer resources at lower cost than smaller providers. To overcome the disadvantage of small clouds, some research proposes architectures, in which small clouds can federate through common virtual interfaces. Therefore, academy and industry ask whether the federation of small cloud providers is economically feasible and can compete with a giant cloud provider. However, it is hard to solve those problems because the specifications of a cloud federation and the conditions of cloud market are unclear. To fill this gap, in this paper, we survey the conceptual background of cloud computing and the federation of small cloud providers. The results of this paper are expected to guide how to define the economic problems on cloud federation and provide constraints to the problems.

Keywords: Cloud Computing, Economic Analysis, Infrastructure-as-a-Service, Platform-as-a-Service, Software-as-a-Service, Service Ecosystem, Economies of Scale, Cloud Federation.

JEL Classification Numbers: D01, D02, D24, D85, L23, L86, M15.

1. Introduction

Cloud is a new paradigm of computing that replaces the paradigm of localized computing and server client architecture [1]. In this paradigm, a cloud provider manages hardware and software to provide clients with an infrastructure as a service, platform as a service, and software as a service through an interface [2]. A client can resolve its scalability problem by paying for using cloud systems of providers on demand [3] [37]. Due to the benefit of scalability, cloud has substituted the conventional computing paradigm (i.e., data centers and software products).

The key to cloud computing is that a cloud provider achieves economies of scale to reduce its operating cost and enhance the elasticity of services [3]. Besides, a cloud provider gains benefit from the clients, whose utility show network externalities, so that two-sided market strategies work [4] [38] [41]. Economies of scale and network externalities make larger cloud providers to be even stronger. A giant cloud vendor can offer low-priced services and the large size of the provider attracts even more clients as the risk of large providers to go bankrupt is low. The revenue from those clients can be used by the provider to upgrade its facility. In addition to this, it is hard for small cloud providers to compete with a giant vendor [41]. For this reason, the concept of cloud federation emerges in academy and in the market. Cloud federation means to "federate disparate data centers or cloud providers, including those owned by separate organizations to enable a seemingly infinite service computing utility" [5][37]. In the federation, small cloud vendors share their resources and clients to achieve the economies of scale, enabling them to compete better with a giant cloud vendor [2]. Therefore, both academy and industry requires a framework that explains the economic feasibility of the cloud federation to answer the question whether small cloud vendors can survive in the market with the relevant technologies. However, it is still unclear what the market conditions for a successful deployment of cloud federation are and in what way the cloud provider business models change through the federation of small cloud vendors.

In this paper, we survey the conceptual background of cloud computing and the federation of small cloud vendors from an economic perspective. In particular, we discuss the economic forces that emerge if federation is introduced to the cloud market. The research questions are: First, what conditions govern the industry of cloud computing, and what business models need to be executed by a cloud provider? Second, how does federation change the business models of the cloud industry? Third, what economic issues arise through the introduction of federation in the cloud industry?

To answer these questions, we depict the technological concepts of cloud federation and their economic implications. In particular, we survey economic theories relevant to issues of cloud federation (i.e., theories on the economies of scale and two-sided market theories), and we discuss the interrelations of cloud computing, federation of clouds, and market environments.

The remainder of this paper is organized as follows. In the next section, we introduce the conceptual background of cloud computing and cloud federation. In section 3, we introduce the economic theories relevant to the cloud federation. In section 4, we describe the details for designing an economic model of cloud federation. Finally, section 5 concludes our paper with a discussion of the implications of our findings.

2. Conceptual Background

2.1. Basic concept of Cloud Computing

Cloud computing is a new paradigm of computing [37]. The National Institute of Standards and Technology (NIST) defines it as a "a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources … that can be rapidly provisioned and released with minimal management effort or service provider interaction" [6]. A cloud provider integrates servers into a cluster, and manages multiple virtual operating systems on a physical system through a hyperviser [7]. With the help of virtualization and clusterization technologies, the workload is distributed into cheap small computing units efficiently. Therefore, a cloud provider can operate its cloud at low operating cost, so that it provides service developers and end users can obtain computing on demand at low prices [1].

The delivery models of cloud computing vary [45] and, recently, the cloud community simply refers to them as "XaaS" [8]. The major delivery models of cloud computing are Infrastructure-as-a-service (IaaS), Platform-as-a-service (PaaS), and Software-as-a-service (SaaS). In brief, IaaS providers package computing resources into virtual machines and cloud communications, while PaaS providers deliver computing platforms, which application developers can use without dealing with different underlying system layers. SaaS providers provide access to applications and databases and manage the underlying infrastructures and platforms [8]. Due to the XaaS delivery models, cloud computing re-organizes the market of IT services forming a cloud ecosystem [41]. It makes computing a utility, as electricity did in the early 20th century [9].

2.2. Federation of Cloud Davids

It has not been discussed in the cloud computing community yet that the factors making cloud computing successful can also threaten the market structure. The number of cloud users determines the potential revenue of a cloud provider through the levying of fees for computing [37]. Economies of scale gives a large cloud provider potentially more revenue through cost savings than a smaller cloud provider [10]. Therefore, a large cloud provider, which entered the market of cloud computing, has an absolute advantage in the competition with its rivals. This situation can be the reason for a cloud provider to lock in its users by slightly deviating its interfaces and protocols from standards [7]. In line with this lock-in behavior, small cloud providers face the difficulty to fulfill users' adoption criteria for operating their cloud ecosystem (e.g., high viability of cloud vendor [38]). Without having many users adopting the cloud though, economies of scale, which are necessary to survive in the cloud computing market, cannot be achieved.

To address this problem, computer science approaches suggest to share resources among cloud providers through a framework with standardized interfaces and standardized goods [11] [39] [40]. Sharing computing resources across cloud providers requires the same framework with standardized interfaces for each participating cloud provider [11]. For example, Cisco designs an architecture (Application Centric Infrastructure (ACI) [13]) for federating clouds. Another approach for federation is to insert a meta-framework among clouds that provides all interfaces that exists in other cloud frameworks [12]. In addition to this, the cloud providers can organize themselves by finding the best standardized good [39] [40].

Through these efforts, cloud users, accustomed to one cloud service vendor, can also utilize other cloud service vendors without spending large effort on migrating their resources to another cloud. In this environment, cloud vendors are free from the strong effect of the number of users and the economies of scale, as they share the computing resources with each other. They do not need to captivate users in their own systems, and they can focus on enhancing their quality of service and reducing their service prices on the basis of shared cloud resources [12] [39] [40].

The federation idea is mainly developed for competing with large cloud vendors like Amazon, Microsoft, and Google [13]. It is also for sure that federation gives more benefit to smaller cloud providers (Davids) than a larger one (Goliath). If a small cloud provider decides to cooperate with its competitors in a federation, it can compete in the market governed by an existing giant cloud provider with which they could not compete without federation owing to the behavior of cloud vendors as described earlier. This strategic cooperation among competitors is called "co-opetition" [14]. However, it is not clear whether the interoperability between clouds that the current technologies enable is economically feasible. Therefore, the cloud computing community needs discussions on the economic feasibility of cloud federation.

In particular, the federation at different levels of the cloud architecture needs to be discussed. Federation at the IaaS level means that VMs of one provider can be executed on the infrastructure of another provider. Federation at the PaaS level means that the management functions on different platforms are identical and can be accessed via the same interface. Federation at the SaaS level means that the data input and output of interfaces are clearly defined and that all interfaces that have ever been offered are supported until the end of the lifetime of the software. This is extremely difficult. For example, a Microsoft Word document can be opened in LibreOffice, but the text style might be broken due to a slight incompatibility.

3. Relevant Economic Theories

3.1. Economies of Scale

Previous literature designates economies of scale as the property that makes cloud computing attractive [3] [7] [15]. Economies of scale describes the economic characteristic that the long-term average cost decreases as the number of products increases in a fixed factor production environment [16]. It is to be noted that the short-term average cost, which is not considered for the economies of scale, might increase due to the inefficiency of using large quantities of input. In this case, the short term average cost shows a U-shaped curve [17].

In case of cloud computing, a large vendor invests a large amount of initial capital on establishing a computing infrastructure, and operates the infrastructure with inexpensive electricity and a small number of system administrators [7]. That is, the fixed cost for providing cloud computing is large compared to the variable cost [37] [43]. Therefore, economies of scale work strongly for cloud computing.

The effect of economies of scale has been shown empirically in a variety of industries that require a huge amount of investment on infrastructure [17] [18] [19]. They investigated the effect of economies of scale by measuring the indicator that is defined as the ratio of the difference of cost to the difference of output. The analysis results provide the rationale for merging industries or companies. For example, the integration between TV and radio industries in Japan saved 12% of cost compared to those provided separately [18]. The integration of Danish hospitals also yielded cost savings [19]. However, the increase in scale does not always result in a company benefit. The water infrastructure industry of the UK showed that the cost efficiency increased when the water industry was separated from the sewerage industry [20].

In theoretical studies, the economies-of-scale property is considered as a linearly decreasing factor price. The total cost is expressed as the sum of quadratic factor costs [21] [22], which are different from cost functions that were assumed in earlier studies. In those earlier studies, factor functions increased linearly according to the factor quantity. The nonlinearity of the cost function of recent studies makes the cost minimization problem complex and the profit maximization problem hard to solve. Therefore, Bayon et al. (2012) introduced infimal convolution to the firm's optimization problem, if the economies of scale is at work [22]. In this method, the smallest cost function is chosen among several cost functions for each segment of the amount of output, and the profit is calculated for each segment on the basis of the chosen cost function.

While the economies-of-scale property is considered as one of the most significant properties of cloud computing, it has not been analyzed in the cloud computing industry. Economic studies on cloud computing simply assume that economies-of-scale benefits a cloud provider. They do not prove the economic origin of this property. They only investigate the effect of the assumed economies-of-scale property on the economic performance. For example, assuming economies-of-scale, a theoretical study proved the model that leasing computational resources from clouds saves cost compared to using on-premise computers [23] [24].

3.2. Network Externalities

Cloud computing providers offers a new platform, on which a number of technology components complement each other. These platforms exist on the infrastructure level, virtual machine management level, and the software level [4]. A cloud provider allows third party agents to utilize its computing resources according to its business model. Then, the third party agents "create value" with partners and "share the value" through putting their own service model on top of an existing one or an combination of existing service models [25]. In this service ecosystem, the role of each company is flexible. Companies can compete or collaborate with one another, while providing users with complementary service. Their decisions are based on their own interests (i.e., profit in case of private companies). Therefore, the platform of cloud computing forms an ecosystem of business entities that is different from previous business ecosystems, in which companies needed to develop all new technologies within the company to compete with its rivals [26] [25].

Previous studies in economics and management science approached the platform issues from the perspective of two-sided markets, which was prompted by two economic articles [27] [28]: Rochet and Tirole (2003) designed an economic model, in which a platform mediates two sides of economic agents to gain its profit from transactions between the two sides, and the demand of one side responds positively to the number of agents on the opposite side [28]. Similarly, Caillaud and Jullien (2003) assumed in their two-sided market model that the utility of an agent on one side depends on the size of the opposite side as well as on the registration and transaction fees levied by a platform provider [27]. With the two sided model above, they showed that there is an equilibrium in the market mediated by platforms and the equilibrium depends on the registration and transaction fees, users' price elasticity of demand, and regulatory conditions. The results imply the feasibility that a few platform providers can dominate the market and that multiple platforms can compete in a market.

The essence of the two-sided market models is that network effect works across sides in the market and that a platform provider needs to enable it to make the ecosystem on its platform work [38] [41].

Network effect means that the utility of an agent depends on the number of agents using the same technology (direct network effect) or the number of complementary technologies (indirect network effect) [29] [41]. It governs the market organization and evolution [30] [29]. To promote the agents on both sides of a platform, a platform provider should determine the "subsidy side" and the "money side" and charge the users of both sides strategically according to their sensitivity to price or quality for harnessing the network effect [31]. The two-sided market approach was applied to a variety of cases including operating systems [32], information products [32] [15] [31], the Internet [33], and advertisements [34].

A platform provider provisions its resources to users such that sellers can gain benefits from the population of users. In general, finding the money-generating side is complicated [42] [44]. For example, Google Maps provides a service to users and charges fees to developers, who utilize the Google Maps professionally (i.e., the traffic from the services of the developers exceeds a threshold). Salesforce.com, however, charges customers for using its platform, levies fee from an application developer when it sells its application to customers [35]. Salesforce.com does not charge for transactions of applications that are offered free-of-charge to users by developers. Sometimes, platform providers have also to decide whether to share its platform with rivals, considering its position with respect to multi-homing costs and differentiation [31].

4. Specifications of Cloud Federation

4.1. Industry Architecture

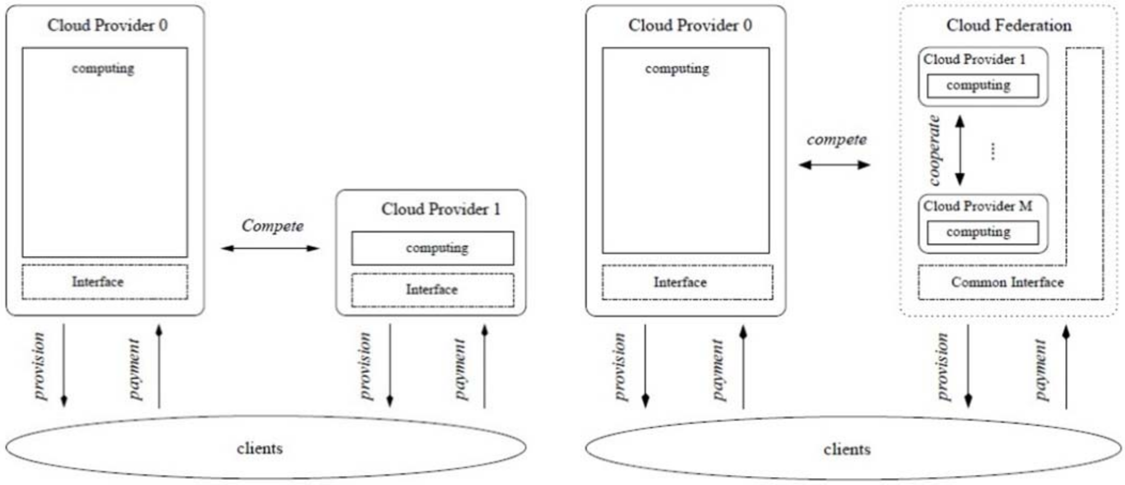
The key to the newly rearranged computing ecosystem is that cloud clients outsource computing for providing their services. This way they can concentrate their effort on their own services, while the former software ecosystem required the computing facility to be in-house.

The mechanisms applied vary according to the delivery models of cloud services, (i.e., software-as-a-service, infrastructure-as-a-service, and platform-as-a-service). In case of software-as-a-service, a client builds up a business relationship with a cloud provider to utilize the software service provisioned by the cloud provider. In case of infrastructure-as-a-service, a cloud provider builds a business relationship with any third party agents to sell its computing resources. The third party agents could be service providers or simply clients. In many cases, a cloud provider establishes a specific contract with the third-party agent, if the third-party agent uses the computing resources for business. In case of personal use, the cloud provider publishes a listed pricing system and customer agreements (e.g., customer agreement of Amazon AWS]. The mechanism in the model of platform-as-a-service is similar to the one of infrastructure-as-a-service but more complicated. Clients can be businesses as well as service users.

Figure 1 (a) describes the competition between two cloud providers in the cloud ecosystem. Each cloud provider provisions its computation service to clients through its specific interface in return for their payment. An interesting characteristic of the cloud market is that a few cloud providers account for the majority of the global market share. For example, about 24% of IaaS and PaaS services were provided by Amazon. Amazon, Salesforce, Microsoft, IBM, and Google together provided about 51% of the IaaS and PaaS services in the 2nd quarter of 2014 [46]. In this environment, any new (small) cloud provider needs to compete with these large cloud providers. The challenge of the small cloud provider is that the economies of scale and network externalities support the large cloud providers.

Figure 1 (b) describes the software ecosystem developed by a federation of cloud providers. The key to cloud federation is a common interface, through which cloud providers and cloud clients can access the resources of all cloud providers. With such a common interface, a third-party agent involved in one cloud platform can utilize the computing resources of another cloud platform without changing any technical set up. By doing so, a federation gives benefits not only to cloud providers but also to third-party agents. From a cloud providers' point of view, computing resources are not shared through the common interface as the provider gets compensated for any resource usage. From an ecosystem perspective, however, clients and service providers can share resources without investing further capital or changing their business models. This extension of computing resources and users enhances the economies of scale of the providers in the federation. The overload of one cloud provider can be moved to another cloud provider with ease. From the clients' point of view, they gain the guarantee of the quality of service without writing additional contracts with multiple cloud providers. The clients might not even recognize that their request to its cloud provider has been fulfilled by another cloud provider. Like clients of a giant cloud, clients of a federation can utilize the computation resources provided by their cloud federation by paying a service fee.

However, the profits of cloud providers within the cloud federation change. A cloud provider within the federation saves cost due to the economies-of-scale by sharing its computing resources and cloud users with other cloud providers of the federation. As the formation of a federation incurs cost for cloud providers through investments in the development of a common interface, making contracts with other cloud providers in the federation on sharing benefits, and establishing procedures on resolving collaboration issues between providers, joining a cloud federation requires a strategic decision of cloud providers considering the benefits and costs.



(a) Goliath vs. David (b) Goliath vs. a Federation

Figure 1. (a) Competition between a Cloud Goliath and Cloud David. (b) Competition between a Cloud Goliath and a federation of Cloud Davids.

4.2. Economic Issues

Through the formation of a federation, cloud providers can share their computing resources (IaaS), platforms (PaaS), or software services (SaaS) [36] [5]. To investigate whether cloud federation is a useful effort of small cloud providers to compete with a giant cloud providers (e.g., Amazon), we discuss three delivery models: IaaS, PaaS, and SaaS. While IaaS has to consider resource allocation, PaaS and SaaS do not.

Table 1. Motivations for cloud federation considering three delivery models (IaaS, PaaS, and SaaS)

Delivery Model	Economies of Scale	Network Externalities
IaaS	• A cloud provider can reduce the cost of maintaining scalability of its service, if a federation is formed. • A cloud provider can improve the resource utilization through cloud federation. • The cost of each cloud provider for managing the computation resources does not decrease, although they form a federation.	• The utility of a client does not change, although the client population increases due to the federation of cloud providers.
PaaS	• A cloud provider does not save the cost of provisioning its service, although the cloud provider participates in a federation.	• The utility of a service developer increases, as a cloud federation increases the client population.
SaaS	• A cloud provider does not save the cost of provisioning its service, although the cloud provider participates in a federation.	• The utility of clients and a service developers increase, as federated clouds increase the enhanced service variety and the client population.

Table 1 summarizes the analysis result for three delivery models (i.e., IaaS, PaaS, and SaaS) and two economic mechanisms that govern the federation of clouds. In detail, it describes how the economic property changes due to the federation from the perspectives of economies-of-scale and network externalities. Our focus is on the rationale according to which a cloud provider should form a federation despite of spending money on the cooperation with its competitors.

In case of IaaS, forming a federation enables a cloud provider to utilize the computation resources of its partner in the federation. Due to this cooperation, a cloud provider can reduce the risk of service failure. The federation enhances the scalability without investments in the infrastructure. That is, a cloud provider can reduce the cost to maintaining the scalability of its service, as it participates in a cloud federation. At the same time, the federation can achieve a better utilization of the resources across all providers in the federation. The cost reduction gives the cloud provider the advantage in price, so that it is competitive to a large cloud provider. However, the federation does not reduce the cost of maintaining the computation resources of a cloud provider. A cloud provider manages its own computation resources independently, even if it is involved in a federation. Therefore, the scale of resources that a company manages does not change. Moreover, the utility of a client is invariant though the client population increases due to the cloud federation. Instead, the utility of a client changes through the decrease in price, which is due to the cost reduction as we can see in the discourse of economies of scale.

In case of PaaS and SaaS, the cloud provider's benefit of forming a federation is different from the one for IaaS. Economies-of-scale do not work in these delivery models, as a cloud provider does not save the cost of provisioning its PaaS and SaaS services within a federation. Therefore, the scalability is expected not to increase through the formation of a federation. Moreover, the cost of managing computational resources is invariant like in the case of IaaS. The cost of managing the software does not change through federation as well. On the other hand, PaaS and SaaS cloud providers gain benefits by forming a federation due to the network externalities on two sides. The utility of a service developer depends on the client population that it can sell its service to. Therefore, the utility of a service developer increases according to the increase in the client population, which comes with forming a federation in the PaaS and SaaS delivery model. In addition to this, in the SaaS delivery model, a client and a developer obtain utility through service variety and service quality. Therefore, forming a federation, which extends the service variety, increases the utility.

5. Discussion and Conclusion

We discussed the rationales that cloud providers form a federation on the basis of two economic properties: economies of scale and network externalities. The benefit that a cloud provider can gain from forming a federation varies over the service delivery model. This is a new result compared to the assumptions made in literature so far.

In case of IaaS, forming a federation is beneficial in terms of the economies of scale. A cloud provider can reduce the cost to maintaining the scalability of its services. In case of PaaS and SaaS, on the other hand, a federation enhances the network externalities because sharing the clients and, for SaaS, sharing the software resources between the cloud providers involved in the federation increases the utility of service developers and the service clients.

Our research is expected to contribute to academia. That is, our results guide designing economic models for cloud federation to analyze their sustainability. Prior research has emphasized economies of scale [10] [7] [41], scalability [3] [8] [38], and network externalities [4] [41] as the keys to cloud computing. However, prior research did not analyze empirically and theoretically whether these properties give benefit to cloud providers, cloud clients, and service developers and how much if they do. For example, a prior study considered economies of scale in its model, just assuming that economies of scale is a valid economic factor [24]. With our study, we filled the gap by analyzing the economic feasibility of cloud federation on the basis of the theories on economies of scale and network externalities. Furthermore, prior research on cloud federation mainly focused on engineering instead of economics, probably assuming that a federation among cloud providers will give benefit for sure. However, as the results of our study showed that the benefit of an advanced technology needs to be analyzed in detail and verified before they can be assumed in models. Our results showed significant differences between SaaS, PaaS, and IaaS cloud services.

In the future, we will extend our work by considering further economic properties that might be at play within cloud federations.

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