A Hedonic Price Index for Cloud Computing Services

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Abstract: Cloud computing is an innovative business model, being developed at a fast pace during the last years, offering many operational and economic benefits to both the demand and the supply side of the ICT market. Infrastructure as a Service (IaaS), which includes control of fundamental computing resources, is expected to be the fastest growing model of public cloud computing. Due to the existence of several IaaS cloud providers, there is increased competition among cloud companies, which develop different pricing models in order to meet the market demand. As a consequence, prices for cloud services are a result of a multidimensional function, shaped by the service's characteristics. The development of a suitable pricing method, based on an appropriate price index able to capture the market dynamics, is an obvious necessity. The aim of this paper is the construction of such a price index, for the IaaS model, using data from a wide range of cloud providers and a large number of price bundles. The hedonic pricing method is used to decompose cloud computing services into their constituent characteristics, obtaining estimates of the contributory value of each resource. According to the results, RAM size, CPU power and subscription turned out to be the most influential factors that shape IaaS pricing.

1 INTRODUCTION

During the recent years, cloud computing has gained enormous popularity across the business world as there is an increased demand for a new business model that can help companies respond faster and cheaper to their constituents' needs, not only in Europe but also worldwide. Its systems and services are being improved and developed at a fast pace, offering operational benefits to both the providers and the consumers of the technology, contributing substantially at the same time to the creation of a competitive environment in the global market (Etro 2009).

Therefore, cloud computing is considered to be a really powerful technological tool and an innovative business model, composed of three service models: Infrastructure as a Service (IaaS), which includes control of fundamental computing resources, such as memory, computing power and storage capacity; Platform as a Service (PaaS) that provides control over the deployed applications and possibly configuration settings for developer platforms and Software as a Service (SaaS), which includes the use of software services accessed through a web browser or a program interface (Mell and Grance 2011). In addition to these, cloud computing has also four deployment models: Private cloud, provisioned for exclusive use by a single organization; Community cloud, used exclusively by a specific community of consumers from organizations that have shared concerns; Public cloud, open for use by the general public and Hybrid cloud, which is a composition of two or more distinct cloud infrastructures (Mell and Grance 2011).

Concerning the above models, public cloud computing receives more attention and the IaaS model gains increased adoption across the business world (Anderson et al. 2013). More specifically, IaaS, which is a foundational cloud delivery service and the most straightforward of the cloud models, provides flexibility and can be a very good solution for companies needing computing resources in the form of virtualized operating systems, workload management software, hardware, networking, and storage services (Hurwitz et al. 2012). Computational power and operating systems are delivered to the customers in an "on-demand" approach. An enterprise that migrates its IT system to IaaS may hire the required resources as needed, instead of buying them (Mell and Grance 2011). According to Gartner's latest report about the public cloud (Anderson et al. 2013), it is expected that IaaS will be the fastest growing area of public cloud computing achieving a compound annual growth rate (CAGR) of 41.3% through 2016, as Figure 1 illustrates.

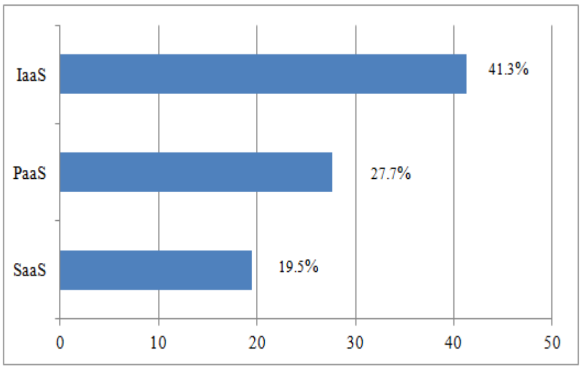

Figure 1: Public Cloud Services - five year (2011-2016) CAGRs (%), by model. Source: Gartner (February 2013)

Currently, there are several public cloud providers in the cloud computing market that provide similar services to customers. A client's choice of which cloud company would host his infrastructure-related services in the long-term depends jointly on the price it has, the Quality-of-Service (QoS) guarantees it offers to its customers and the satisfaction of the advertised guarantees (Vinu Prasad et al. , Siham et al. 2012). Cloud computing works, in general, on a "pay-as-you-go" basis, giving the option to the user to pay for what they use; meaning that the customer is charged for each computing resource (e.g. RAM, CPU, storage) separately, usually per unit-hour (Martens et al. 2012). On the other hand, it is true that the battle for a dominant market share grows the competition among cloud companies and leads to the development of new pricing schemes in order to meet the market demand. As a result, several packages of different resources are offered in attractive tariffs and they are continually fitted to the changing preferences and increasing needs of customers. Furthermore, there is an option somewhere in the middle, as there are some cloud providers who offer predefined sets of some resources, usually memory and CPU are bundled, whereas users can select simultaneously on their own some other computing characteristics, such as storage size (Martens et al. 2012, Andra 2013).

Finding the right combination of the available resources is critical for a business to achieve the best value when creating its own cloud bundle of services. As any bundle consists of various characteristics, valued differently by each consumer, there are a number of questions that arise in the cloud computing context, such as:

- How customers' choices and preferences for IaaS affect the pricing of the corresponding resources.
- Which characteristics are truly independent from one another, while at the same time being the most important for shaping the pricing of IaaS.

Towards this direction, multiple cloud providers have already developed cost estimator tools, which are used to help customers evaluate IaaS services, deciding the most suitable for their needs. In addition, another similar approach is considered to be a broker model that acts as an intermediary between consumers and providers. Both of these methods are mainly based on asking users some questions about the amount of computational power, memory, storage requirements, data transfer and they subsequently offer a monthly estimate for price, for the selected bundle (Hurwitz et al. 2012) or the most cost-efficient tariff option among many different providers in the case of a broker (Jörg et al. 2014). However, none of these tools is capable of identifying the cheapest cloud hosting provider due to the fact that this is a choice that depends exclusively on the clients' computing needs and, furthermore, price is considered to be a multidimensional function, where many factors should be taken into account (Siham et al. 2012).

Into that context, this paper tries to describe the current mechanism of pricing and reveal the dynamics which drive the pricing of cloud computing services. For this, it provides an empirical analysis of IaaS pricing, by constructing a price index based on a hedonic pricing method.

The remainder of the paper is structured as follows: Section 2 presents a brief literature review of the previous work regarding the pricing methods of cloud computing, while in Section 3 there is a theoretical approach of hedonic functions analysis and price indices. The empirical study and the evaluation of hedonic regression model together with discussion are described in Section 4, and finally, Section 5 concludes, providing directions for future research.

2 PRICING MODELS OF CLOUD COMPUTING

In a cloud computing environment, an Infrastructure-as-a-service demand is considered as an access to the system resources, such as CPU, memory and disk. Resource allocation is a really challenging task because of the different pricing models the providers use. In general, cloud hosting providers must offer a good pricing model that does not bring any loss to neither the provider nor the consumer and maximizes the social surplus of the corresponding market. It is not usually easy to reach a point where both sides agree with the price set. A user is always willing to pay a lower price for the resources requested, whereas a provider should not want to go beyond the lowest price that gives him no profit (Andra 2013).

Currently, there are many cloud vendors that follow a fixed pricing strategy, meaning that customers pay for what they use but not for what the cloud services value (Vinu Prasad et al.). One of the most common pricing schemes of this category is the “pay-as-you-go” model, which charges the users for just the services they need, paying only for the required computing instances and just for the time they use them. In the case they need more resources, they simply request them from the provider (Grossman 2009). Another fixed pricing model is based on subscription, setting a standard price for the required resources according to a longer period of subscription (Al-Roomi et al. 2013). However, these static approaches of pricing have some limitations, due to the fact that they reserve computational resources in advance and it is often hard to satisfy both the cloud vendors’ and cloud users’ requirements.

Hence, dynamic pricing is usually the key solution to the above problems. It is a method in which the price for each bundle of resources is based on a number of factors, such as availability, time, the service features and according to the forces of the demand and supply of a real-time market (Andra 2013, Al-Roomi et al. 2013). Mihailescu and Teo (2010) proposed such an auction-based pricing strategy for federated clouds, in which resources are shared among many cloud service providers. Rohitratana and Altmann (2012) used an agent-based simulation of four different pricing models that indicated that the Demand-Driven (DD) pricing scheme was the best approach in ideal cases. Li et al (2011) introduced a real-time pricing algorithm for cloud computing resources. It analyzed some history utilization data and it found the final price that was mostly beneficial for the provider because it reduced its costs, allowing at the same time resources to be used more effectively. Moreover, there are some pricing methods that are mostly driven by competitors’ prices (Rohitratana and Altmann 2010) and some others based on the amount of money users are ready to pay (Ruiz-Agundez et al. 2011). All of the above pricing methods are fair enough for the customers’ side.

Both of the above categories of pricing models, especially the dynamic one, take into consideration some of the service’s most important characteristics. The construction of price indices is generally used for this purpose, seeking to estimate the extent to which each characteristic affects the total price of a service bundle. Among the most common and widely used approaches is the hedonic pricing method (Triplett 2004). It was primarily developed seeking to capture the effect of environmental and housing attributes in the context of the housing market (Goodman 1978) and to adjust for quality change for automobiles (Griliches 1961). In (Chanel et al. 1996) a price index for paintings, based on regressions using the full set of sales, was constructed and the idea that goods are valued for their utility-bearing characteristics can be found in (Rosen 1974). As far as information and communication technologies are concerned, hedonic price indices have been widely used for personal computers (Pakes 2002, Berndt et al. 1995) taking quality changes into account and for microcomputers and printers using evidence from France (Moreau 1996). A hedonic pricing approach has been also proposed in (Jörg et al. 2014) to estimate price evolution of telecommunication services based on data across Europe and in (Siham et al. 2012) the hedonic pricing method was applied to make cloud pricing plans more transparent.

3 HEDONIC PRICE INDICES

Hedonic methods refer to regression models in which a product’s (or a service’s) prices are related to product characteristics and the observed price of a product (service) is considered as a function of these characteristics. The main assumption hedonic methods are based on, is that a service is a bundle of characteristics and that consumers just buy bundles of product characteristics instead of the product itself. A hedonic method decomposes the item being researched into its constituent characteristics, and obtains estimates of the contributory value of each characteristic, provided that the composite good can be reduced to its constituent parts and that the market values those constituent parts.

According to the definition of (Triplett 2004): "A *hedonic price index* is any *price index that makes use of a hedonic function*. A *hedonic function* is a relation between the prices of different varieties of a product, such as the various models of personal computers, and the quantities of characteristics in them".

These methods can be used to construct a quality-adjusted price index of a service. An informative overview of the hedonic methods and how they are constructed can be found in (Berndt 1991, Triplett 2004). Moreover, as shown in (Rosen 1974) consumer chooses from a large number of product varieties without having the ability to influence prices. As a consequence, consumers maximize utility and producers maximize profits. In hedonic studies it is possible to adjust the price of a service for its quality not quantity. All of them are based on some estimated coefficients that are inflicted on the characteristics of the products in two periods; *m* and *m + 1*. It is possible to estimate the coefficients separately, for each evaluate period of time, or consider the observations of two or all periods together and estimate a common set of coefficients, seeking to reveal the general trend.

The advantage of this method is that the necessary calculations are easy to implement. Hedonic methods are also very fast to apply but the disadvantage is that index price can change even if no new products exist, or if all prices remain the same. Among the strengths of a hedonic pricing method are that it can be used to estimate values based on actual choices and its versatility, since it can be adapted to consider several possible interactions between market goods and environmental quality.

The hedonic price indices are commonly used as approximations to find how much money a consumer would need in period *m+1* relatively to the amount of money required in period *m*, keeping the same level of utility. The solution to this problem is to determine the consumer's profile and his reaction to a varied and fast-changing supply of products. The main problem towards this direction is that each consumer has potentially different needs and requirements No matter what profile is decided, it will be a hypothesis and an assumption that will correspond to a specific model. In addition to this, a consumer's desire is not stable, something quite reasonable since there is a great offer as technology becomes cheaper and more attractive.

A hedonic function $f(X)$, which relates a number of the product's characteristics with the corresponding price as:

$$P_i = f(X_i) \quad (1)$$

where P_i is the price of a variety (or a model) *i* of the considered product and X_i is a vector of characteristics associated with the specific variety. The hedonic function is then used, for a number of different characteristics among the varieties of the product and the price index is calculated. As soon as the characteristics to be considered are determined then, for *N* varieties of the product (or service) the following equations must be evaluated:

$$P_i = b_0 + b_1 \cdot X_{1i} + b_2 \cdot X_{2i} + e_i, \quad i = 1, \ldots, N \quad (2)$$

where b_i are the regression coefficients that have to be estimated and e_i is the regression residual of the assumed functional form. The regression coefficients value the characteristics and they are often called implicit prices, because they indicate the prices charged and paid for an increment of one unit of the corresponding characteristic. Implicit prices are much like other prices, they are influenced by demand and by supply. In some cases the natural logarithm (ln) of the price is considered, instead of the actual value. Furthermore, the functional form of the index can be nonlinear.

In the case that the prices span between two (or more) periods of time *m* and *m + 1*, the equations to be evaluated are

$$\begin{aligned} &P_{im} = b_0 + b_1 \cdot X_{1i} + b_2 \cdot X_{2i} + e_{im}, \\ &i = 1, \ldots, N \\ &P_{im+1} = b_0 + b_1 \cdot X_{1i} + b_2 \cdot X_{2i} + e_{im+1}, \\ &i = 1, \ldots, N \end{aligned} \quad (3)$$

In the context of this work, the vector of characteristics *Xi*, corresponds to the configuration of the IaaS cloud services that affects the price, including characteristics such as RAM size, number of CPUs, memory size, bandwidth etc. The description of these parameters is given in the next section.

The importance of a price index is that it can be used to determine suggested prices for combinations of the characteristics that were not included, or they were not available, when the index was constructed.

4 PRICE INDEX CONSTRUCTION

This section describes the empirical study design, contains the evaluation of the hedonic price index methodology for cloud computing services, the construction of a corresponding index and discussion of the results.

The price index is constructed for the IaaS cloud computing, the most straightforward cloud service. Data collection was based on Cloudorado (http://www.cloudorado.com), a price comparison service of cloud computing providers. Cloudorado is also a price calculator for multiple cloud hosting providers, since the comparison is performed by calculating price for individually set server needs. It currently focuses on providing pricing bundles for IaaS providers. The number of the collected price bundles is 2354, by 25 providers, shown in **Error! Reference source not found.**

Table 1 Cloud IaaS providers

Amazon
atlantic.net
Bitrefinery
CloudSigma
Dimensiondata
eApps
ecloud24
Elastichosts
Exoscale
GIGENET
GOGRID
HYVE
JoyentCloud
Lunacloud
M5
Ninefold
OPENHOSTING
Rackspace
SERVERMULE
Storm
StratoGen
Terremark
VPSNET
Windows Azure
Zettagrid

Google is not included among the providers since it does not offer price bundles but it rather charges for each CPU and each GB of storage and memory capacity. The price bundles are specified by the resources presented in Table 2, together with the considered values. These characteristics participate as variables in the hedonic pricing model.

Table 2: IaaS characteristics.

Characteristic	Description	Values
CPU	CPU power	2x, 4x, 6x / 3x, 5x, 7x
RAM	RAM size in Gigabytes (GB)	1, 4, 16, 32
Storage	Measured in GB	100, 1000
Transfer_Out	Number of bytes sent by server to Internet per month. (GB)	5, 10000
OS	Operating System of the server	Linux, Windows
Subscription	Indicates if there should be a subscription	No, Yes (corresponds to 1 year subscription)

Data correspond to the IaaS services offered by cloud providers who use different pricing models. The study started by selecting specific computing requirements (e.g. 2xCPU, 1GB RAM, 50GB Storage, 5GB Tranfer-Out, Linux) but due to the fact that many of the providers (e.g. Amazon, Rackspace, GoGrid) use price bundling, the best package of resources, which was most close to each customer's needs, was chosen every time. Prices range between $31 and $3,318 per month and there are observable differentiations depending on the existence of a subscription, while the duration of the subscription does not affect the price substantially. The operating system parameter (OS) and the subscription characteristics participate as dummy variables. The values for the OS are 0 for Windows and 1 for Linux and, regarding the subscription, corresponding values are 0 for no subscription and 1 for a subscription.

Not surprisingly, the most popular geographical continent for providers is North America, with 19 out of the 24 to have datacenters located there, followed by Europe, with 13 providers. Australia and Asia follow with 8 and 6 providers, respectively, and Africa comes last with just 1 provider.

Among the limitations of the collected dataset is that there are a few more characteristics participating in the construction of the price bundling, which were not considered into this study. These characteristics are the Transfer In (the number of bytes received by server from the internet per month), the Time On (proportion of the day the server is available) and the option that the CPUs, the RAM and the storage can be distributed among more than one physical server. The value of the Transfer In characteristic does not contribute at a substantial level to the shaping of the pricing bundles, because many cloud providers such as Amazon and ecloud24 charge customers only for the outgoing traffic and the others include it as a small amount in the total price of services. Therefore, with no loss of generality, the Transfer In attribute was considered to be at 1GB per month. As far as Time On is concerned it was set at a level of 100% availability per day. The default offered value of non-distributed resources was also considered.

Moreover, some non-functional factors, such as availability and reliability of resources or the lack of fulfilling the agreements between consumers and providers, were not considered in the price model, as variables. Inclusion of these characteristics is an interesting extension of the model, since it may reveal their potential to affect the price of a cloud offering. This needs to be empirically proven through the execution of many different scenarios.

The results of the hedonic pricing method are summarized in

Table 3**Error! Reference source not found.**.

Table 3 Results of hedonic method

Coefficients	Value
Constant	130,499*** (35,42)
CPU	14,532** (6.41)
Storage	0,249*** (0.02)
RAM	20,434*** (0.86)
OS	-16,91 (2.29)
Transfer_OUT	0,076*** (0.002)
Subscription	-85,82 (20.28)

*** p<.01, **p<.05, *p<.1, n.s. not significant

The calculated R^2 value is 57.91%, indicating that although a great portion of the uncertainty is described by the model, the linear form of the model may not be the most appropriate to describe the pricing index and alternative formulations could also be considered.

As observed, all parameters are significant and they contribute to the shaping of the price. Subscription is the parameter contributing more to the price index, followed by the RAM size and the CPU. The high value of the constant, which represents a fixed monthly fee, supports the finding that the subscription is a crucial parameter. Storage does not seem to affect the price very much. The choice of the operating system affects pricing at a high level, since Linux reduces the price of the bundles by a factor of 16.91.

5 CONCLUSIONS

The hedonic pricing method was used in this work, in order to develop a price index for the Infrastructure as a Service cloud computing services. The evaluation of the method was based on the linear hedonic model and the data were collected for a number of 22 providers, corresponding to more than 2300 price bundles.

The results indicate that, apart from the constant parameter which indicates the importance of the subscription, a finding that is also supported by the high value of the subscription parameter, the RAM size and the CPU are also of substantial importance and significance. On the contrary, the storage and the transfer out parameters seem to affect the pricing procedure less.

As in most cases, there are some certain limitations in this work, which in turn constitute its further extension and indicate directions for future research. Among them is the use of nonlinear functional forms in the hedonic formulation, seeking to improve the accuracy of the pricing index. The value of R^2 achieved indicate that it would be worth testing. Apart from the general price index considering price bundles across all providers, the construction of an index for each provider would be of particular interest, mainly for comparison reasons.

The construction of price indices for the other cloud computing models, namely the software as a service (SaaS) and the Platform as a Service (PaaS), where literature has little to present, would be another important, as well as interesting research direction.

In any case, the existence of a price index for the cloud services can provide very useful information, not only regarding the pricing schemes but also regarding the market of cloud itself and could suggest optimal pricing approaches of the cloud services.

REFERENCES

Al-Roomi, M., Al-Ebrahim, S., Buqrais, S. and Ahmad, I. (2013) 'Cloud Computing Pricing Models: A Survey', *International Journal of Grid & Distributed Computing*, 6(5).

Anderson, E., Eschinger, C., Wurster, L., de Silva, F., Contu, R., Liu, V., Biscotti, F., Petri, G., Zhang, J. and Yeates, M. (2013) 'Forecast overview: Public cloud services, worldwide, 2011-2016, 4Q12 Update', *Gartner Inc., February*.

Andra, R. S. (2013) 'Investigating Pricing and Negotiation Models for Cloud Computing'.

Berndt, E. R. (1991) *The practice of econometrics: classic and contemporary*, Addison-Wesley Publishing.

Berndt, E. R., Griliches, Z. and Rappaport, N. J. (1995) 'Econometric estimates of price indexes for personal computers in the 1990's', *Journal of Econometrics*, 68(1), 243-268.

Chanel, O., Gérard-Varet, L.-A. and Ginsburgh, V. (1996) 'The relevance of hedonic price indices', *Journal of Cultural Economics*, 20(1), 1-24.

Etro, F. (2009) 'The economic impact of cloud computing on business creation, employment and output in Europe', *Review of Business and Economics*, 54(2), 179-208.

Goodman, A. C. (1978) 'Hedonic prices, price indices and housing markets', *Journal of Urban Economics*, 5(4), 471-484.

Griliches, Z. (1961) 'Hedonic price indexes for automobiles: An econometric of quality change' in *The Price Statistics of the Federal Goverment*, NBER, 173-196.

Grossman, R. L. (2009) 'The case for cloud computing', *IT professional*, 11(2), 23-27.

Hurwitz, J., Kaufman, M. and Halper, D. F. (2012) 'Cloud Services for Dummies', *IBM Limited Edition, John Willy and Sons*.

Jörg, G., Hiemer, J. and Hinz, O. (2014) 'A Cloud Computing Broker Model for IaaS resources', in *Proceedings of the European Conference on Information Systems (ECIS) 2014*, Tel Aviv, Israel, June 9-11,

Li, H., Liu, J. and Tang, G. (2011) *A pricing algorithm for cloud computing resources*, translated by IEEE, 69-73.

Martens, B., Walterbusch, M. and Teuteberg, F. (2012) *Costing of cloud computing services: A total cost of ownership approach*, translated by IEEE, 1563-1572.

Mell, P. and Grance, T. (2011) 'The NIST definition of cloud computing'.

Mihailescu, M. and Teo, Y. M. (2010) *Dynamic resource pricing on federated clouds*, translated by IEEE, 513-517.

Moreau, A. (1996) 'Methodology of the price index for microcomputers and printers in France', *Industry Productivity: International Comparison and Measurement Issues*, 99-118.

Pakes, A. (2002) *A Reconsideration of Hedonic Price Indices with an Application to PC's*, National Bureau of Economic Research.

Rohitratana, J. and Altmann, J. (2010) 'Agent-Based Simulations of the Software Market under Different Pricing Schemes for Software-as-a-Service and Perpetual Software', *Economics of Grids, Clouds, Systems, and Services, ser. Lecture Notes in Computer Science, Altmann et al., Eds. Springer Berlin/Heidelberg*.

Rohitratana, J. and Altmann, J. (2012) 'Impact of pricing schemes on a market for Software-as-a-Service and perpetual software', *Future Generation Computer Systems*, 28(8), 1328-1339.

Rosen, S. (1974) 'Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition', *Journal of Political Economy*, 92, 34-55.

Ruiz-Agundez, I., Penya, Y. K. and Bringas, P. G. (2011) *A flexible accounting model for cloud computing*, translated by IEEE, 277-284.

Siham, E. K., Schlereth, C. and Skiera, B. (2012) 'Price comparison for infrastructure-as-a-service'.

Triplett, J. E. (2004) *Handbook on hedonic indexes and quality adjustments in price indexes, science, technology and industry working papers,* OECD publishing.

Vinu Prasad, G., Rao, S. and Prasad, A. S. 'A Combinatorial Auction Mechanism for Multiple Resource Procurement in Cloud Computing'.