Pricing in Infrastructure Clouds – An Analytical and Empirical Examination

Completed Research Paper

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Abstract

With the increasing maturity of the cloud computing market, specifically in the Infrastructure as a Service (IaaS) domain, adequate pricing of services has become a crucial success factor for providers. In this work, we take a threefold approach to examine the current situation concerning pricing in the IaaS market. Based on an initial literature review, we find that pay-as-you-go pricing is perceived as the dominant scheme by the scientific community. Based on this notion, we discuss other pricing schemes with respect to their advantages, disadvantages, and challenges for a cloud provider. These results are complemented by an empirical study, in which we identify pay-as-you-go and subscription pricing as the dominant options that are practically applied in the IaaS market today.

KEYWORDS

Cloud computing, infrastructure, IaaS, pricing, scheme, mechanism, analytical, empirical, study, examination.

Introduction

The idea to centrally and dynamically provision IT services via (public) networks – that is, the quintessence of cloud computing – is not an invention of modern times, but already saw it practical realization in the mainframe-oriented time-sharing models of the 1960s (Cusumano, 2010). Yet, the following decades rather brought along a *decentralization* of IT with the widespread deployment of personal computers, both in business and private life. Since the beginning of the new millennium, this trend has reversed once again, marked by buzzwords such as application service providing – which can be seen as a predecessor of today's Software as a Service offers (Weinhardt et al., 2009) – and thin clients, finally cumulating in the concept of "cloud computing".

Through the use of new technologies, most notably virtualization, cloud computing permits the pooling of resources, and hence, the flexible, cost-efficient provision of IT capacities. While Amazon with its Amazon Web Services can arguably be seen as a pioneer of the industry (Qian et al., 2009), numerous providers have entered the market in recent years. Hence, with increasing competition among providers, an adequate pricing for cloud services has become a crucial success factor. This specifically applies for Infrastructure as a Service (IaaS) offers such as Virtual Machines (VMs) and storage, which are characterized by increasing standardization and thus, limited lock-in effects and high substitutability.

Based on this notion, we examine the issue of pricing in infrastructure clouds in this paper. In this context, we strive to answer the following research questions:

1. *What is literature view on pricing in cloud computing and specifically, IaaS?*
2. *What are the theoretic pros and cons of selected pricing mechanism from the standpoint of an IaaS provider?*
3. *Which pricing mechanisms are practically applied in the IaaS market today?*

We believe that the results of our work can be of interest to both researchers and practitioners in the area of cloud computing. Notably, for fellow scientist, this paper provides a consolidated overview of the current literature view on cloud pricing and an empirical "reality check" of the main results. Furthermore, our work can aid (prospective) cloud providers in the selection of an adequate pricing mechanism and offers them a broad impression of the current market situation.

The remainder of this paper is structured as follows: In the following section, we discuss the scientific view on pricing in IaaS clouds, based on a literature review. Subsequently, we discuss a selected set of popular pricing mechanisms with respect to their theoretical applicability for cloud-based infrastructure services. As a complement to these analytical findings, we present the results of a quantitative study in the IaaS market. The paper closes with conclusions.

Literature View on Cloud Pricing

In the first part of our research, we aimed to identify the literature view on cloud pricing. For that purpose, we identified a set of recent papers that deal with cloud computing and make explicit statements on the pricing aspect. In this process, we used the *Google Scholar* scientific search engine as a starting point and identified further relevant papers based on our initial results. In the search process, we used a combination of terms such as "cloud", "cloud computing", "definition", "pay", "payment", and "pricing".

We focused on papers that had received at least 50 citations as of October 2013 according to Google Scholar. These contributions can be considered to have had significant impact on the perception and understanding of cloud computing within the scientific community. While other metrics, such the corresponding outlet's impact factor or ranking, may have also been considered in the selection process, we believe that the number of citations constitutes the most obvious and direct measure of an individual paper's relevance.

Nevertheless, it should be acknowledged that our approach, which is based on the previously described Google Scholar search, has potential limitations: First, Google Scholar's index may be incomplete, both with respect to the indexed papers and the indexed citations; second, our search terms may be inadequate to identify all papers that are potentially of interest to the specific research question.

Table 1 summarizes the results of our literature review, listing a set of 17 scientific sources and the respective statements on cloud pricing. As can be clearly seen, there appears to be a consensus within the scientific community that cloud services are priced using a "pay-as-you-go" (or "pay-per-use") scheme, i.e., that users are charged costs that linearly increase with their respective resource utilization.

Table 1: View on pricing in cloud computing in the scientific literature

Source	Statement on pricing
Armbrust et al., 2009	"...made available in a **pay-as-you-go** manner to the general public..."
Buyya et al., 2009	"Consumers are then able to pay service providers **based on their usage** of these utility services"
Durkee, 2010	"The essential characteristics of cloud computing that address these needs are: ... **Pay-per-use**. Much like a utility, cloud resource charges are based on the quantity used."
Foster et al., 2008	"In a cloud-based business model, a customer will pay the provider **on a consumption basis**, ... such as electricity, gas, and water ..."
Gong et al., 2010	"... when a user use the storage service of cloud computing, he just **pay the consuming part** without buying any disks ..."
Grossman, 2009	"Cloud computing is usually offered with a usage-based model in which you **pay for just the cloud resources that a particular computation requires**"

Ibrahim et al.,2011	"Cloud computing enables users to perform their computation tasks in the public virtualized cloud using **a pay-as-you-go style**."
Leavitt, 2009	"…like a public utility, **pay based on their usage level**."
Mell and Grance, 2011	„Typically this is done on a **pay-per-use** or **charge-per-use** basis. "
Napper and Bientinesi, 2009	"The cloud computing model provides flexible support for '**pay as you go**' systems"
Schubert et al., 2010	"**Pay per use**. The capability to build up cost according to the actual consumption of resources is a relevant feature of cloud systems"
Subashini and Kavitha, 2011	"The cloud offers several benefits like fast deployment, **pay-for-use**, lower costs…"
Vaquero et al., 2009	".. access to resources on **a pay-per-use basis** …"
Wang and von Laszewski, 2008	"…users could buy IT hardware, or even an entire data center, **as a pay-as-you-go** subscription service."
Xu, 2012	"IaaS promotes a **usage-based payment scheme**, meaning that customers pay as they use."
Zhang et al., 2010	"Cloud computing uses a **pay-as-you-go** pricing model"
Zhu et al., 2011	"The '**pay-as-you-go**' model of a public cloud would greatly facilitate small businesses […] **they pay just for the computing and storage** they have used …"

This consensus has probably been strongly driven by the seminal and heavily cited papers by Armbrust et al. (2009) and Buyya et al. (2009), which predicted the development of cloud computing into a utility, similar to water or telephony, and is also compatible with the well-known definition of cloud computing that was last updated by the Mell and Grance from the National Institute of Standards & Technology (NIST) in 2011.

In summary, with respect to our first research question, we conclude that pay-as-you-go is seen as the dominant pricing mechanism for cloud services in the literature.

Analytical Examination of Pricing Mechanisms in the Context of IaaS

The second part of our research focused on the analytical examination of different pricing mechanisms with respect to their suitability for the IaaS market. For that purpose, we identified six major pricing mechanisms and subsequently assessed them from the viewpoint of an IaaS provider. The results are provided in Table 2 – along with the literature sources that form the basis of our assessment – and will be discussed in detail in the following.

In principal, the listed pricing mechanisms can be distinguished into two major classes, depending on the interaction type. For *non-interactive* mechanisms, prices are unilaterally set by one party – usually the provider of cloud services –, i.e., the other party – usually the consumer – does not have any influence on the price ("take it or leave it"). In contrast, with *interactive* schemes, the price of a service is actively negotiated between the provider and consumer (Hinz and Creusen, 2009; Skiera et al., 2005).

To start with, *pay-as-you-go* (also known as pay-per-use) pricing has been identified as the pricing scheme that is commonly associated with cloud computing in the current literature. It perfectly matches the "elasticity" characteristic that is connected with cloud computing in the public perception. Furthermore, pay-as-you-go pricing is characterized by its simplicity, which makes marketing the cloud products to consumers easier for the cloud provider. However, pay-as-you-go pricing requires extensive logging of the actual cloud usage through the provider. Cash flows are difficult to predict, since consumer demands may fluctuate over time, resulting in variable revenue streams. In addition, consumers' willingness to pay may be insufficiently skimmed, since each user is charged the identical amount of money for a certain service. Hence, the determination of an optimal price is among the key challenges in pay-as-you-go pricing, as is the determination of required capacities.

Subscription models alleviate some of these problems. Since users commonly make an upfront commitment, both cash flows and future capacity demands are easier to predict. This model also offers advantages with respect to customer retention, since users are less likely to switch providers once they have made an upfront payment. Also, similar to pay-as-you-go-pricing, subscription models are easy to understand and market. However, they also lead to an insufficient skimming of consumers' willingness to pay, since prices are difficult to differentiate between different user groups. Thus, adequate price-setting can be challenging. Furthermore, subscription models contradict the previously mentioned "elasticity" property of cloud computing, because consumers have to make long-term upfront commitment.

Flatrate models can be seen as a specific flavor of subscription schemes. Since customers pay a static amount of money per time period and often make a long-term commitment, cash-flows can be forecast relatively easily. In addition, accounting is substantially easier – at least in a true flatrate model without usage constraints –, because the necessity to track service use is eliminated. Flatrate models are also simple to market; they further enhance customer retention, specifically when consumers have to make a long-term commitment. Lastly, as part of the so-called flatrate bias, customers may overestimate their actual resource demand and hence be willing to pay a premium price for a service compared to a pay-as-you-go scheme. On the downside, the forecast of customer demands is difficult, and the willingness to pay may be insufficiently skimmed, since all consumers are offered the identical price. Hence, price-setting is also among the top challenges for flatrate models. Furthermore, the adequate capacitation of the infrastructure is difficult to decide; with a flatrate model, users tend to consume more resources than actually required, resulting in high resource utilization and potentially a lack of stability.

Freemium pricing is frequently applied for digital goods, such as smartphone apps, where service providers often offer a free (limited) version and a paid (enhanced) version in the market. Freemium pricing can have a beneficial effect in advertising, since consumers may try out a product without any upfront payment or commitment. It hence permits customers to gain initial experience with the product, allowing them to assess its inherent value. Freemium pricing also allows to quickly gain a customer base, which is specific interest in market entry. However, since the number of consumers who are willing to switch to the paid version of a service is difficult to estimate, a provider faces an uncertain cash flow. In addition, freemium models involve the complex challenge of adequately designing the product versions, such that users have an incentive to switch to the paid version of the product.

Auctions constitute a common interactive pricing scheme. Their main benefit over the previously named schemes is that it permits to effectively skim the consumers' willingness to pay by differentiating prices between different customers (groups). However, with a multitude of different auction mechanisms being available, the appropriate design of the auction process constitutes a major challenge for the provider. In addition, auctions are inherently more complex than other pricing schemes, and thus, more difficult to market. In addition, since auction prices may fluctuate over time, the prediction of cash-flows is difficult when such model is applied.

Lastly, *reversed pricing* schemes may come both in the form of interactive and non-interactive mechanisms. For example, with Name-Your-Own-Price (NYOP), consumers make a price suggestion to the provider, which he/she subsequently accepts or rejects. In contrast, with a Pay-What-You-Want (PWYW) scheme, the provider will accept any offer, possibly subject to a certain pre-defined constraint. Both schemes may have a huge effective advertising effect, because consumers are given the ability to name a fair value for a service, rather than having to accept a provider-defined price. Furthermore, the consumers' willingness to pay may be more efficiently skimmed than in static schemes, at least with NYOP mechanisms. However, reversed pricing is more complex with respect to implementation and accounting, e.g., because the provider has to specify an adequate acceptance threshold in NYOP. In addition, as for all interactive pricing schemes, the cash flow is difficult to predict, because the willingness to pay of consumers may vary over time. Also, specifically for NYOP schemes, the provider faces the challenge of keeping his/her acceptance threshold constantly concealed.

In conclusion, regarding our second research question, we find that all six considered pricing have advantages and drawbacks for a cloud provider. Non-interactive pricing schemes, such as pay-as-you-go or subscription, are usually easy to understand and market. However, they insufficiently skim the willingness to pay of the (prospective) consumers and make it challenging to set an optimal product price. In contrast, interactive pricing schemes promise higher revenues and permit to differentiate prices between consumer groups. Yet, these mechanisms are more complex to understand and market and are difficult to appropriately design.

Table 2: Assessment of different pricing schemes from a cloud provider perspective

Pricing Model	Advantages	Disadvantages	Challenges
Pay-as-you-go / Pay-per-use	Simple Pricing Model (Samimi and Patel, 2011; Weinhardt et al., 2009) Optimal transformation of the characteristics of Cloud Computing (Lai, 2005; Koehler et al., 2010; Armbrust et al., 2010)	Complex collection of usage (Lai, 2005; Armbrust et al., 2010) Inefficient skimming of payment willingness (Lai, 2005) Cash flow difficult to predict (Lai, 2005) Negative effect on customer retention	Identification of the optimal price (Abhishek et. al.,2012; Lai, 2005; Skiera et al., 2005) Prediction of necessary capacities (Armbrust et al.,2009; Lai, 2005; Koehler et al., 2010)
Subscription	Simple Pricing Model (Samimi and Patel, 2011; Weinhardt et al., 2009) Simple accounting (Fishburn and Odlyzko, 1999) Necessary capacity and proceeds easy to predict (Fishburn and Odlyzko, 1999) Positive effect on customer retention	Inefficient skimming of consumers' willingness to pay Suboptimal transformation of cloud computing characteristics	Identification of the optimal price (Lehmann and Buxmann, 2009)
Flatrate	Simple Pricing Model (Samimi and Patel, 2011; Odlyzko, 2000) Simple accounting (Fishburn and Odlyzko, 1999) “Flatrate bias”, i.e., higher willingness to pay (Lehmann and Buxmann, 2009; Odlyzko, 2000) Proceeds easy to predict (Fishburn and Odlyzko, 1999) Positive effect on customer retention	Required capacities (Odlyzko, 2000) Inefficient skimming of consumers' willingness to pay	Identification of the optimal price (Lehmann and Buxmann, 2009) Lack of infrastructure stability due to increased usage (Odlyzko, 2000)
Freemium	Hugh effective in advertising Permit fast growth of the customer base (Anderson, 2009) Permits initial consumer assessment of experience goods	Cash flow difficult to predict	Appropriate feature differentiation between the free and paid versions (Anderson, 2009) Creation of incentives to pay (Anderson, 2009; Clement and Schreiber, 2010)
Auction	Effective skimming of payment willingness (McAfee and McMillan, 1988; Clement and Schreiber, 2010)	Complex pricing model (Hinz and Creusen, 2009) Complex design process (Hinz and Creusen, 2009) Cash flow difficult to predict	Optimal design (Hinz and Creusen, 2009; Skiera et al., 2005) Explanation of the pricing model (Hinz and Creusen, 2009)
Reverse Pricing	Highly effective in advertising s (Hinz and Creusen, 2009) Efficient skimming of consumers' willingness to pay (Shapiro and Zillante, 2009)	Complex pricing model (Hinz and Creusen, 2009) Cash flow difficult to predict	Optimal design (Shapiro and Zillante, 2009; Skiera et al., 2005) Confidentiality of the price limit and the successful bids (Bernhardt et al., 2005)

Empirical Study of Pricing Mechanisms in the IaaS Market

In the third and final part of our research, we aimed to complement our analytical findings with empirical data from the IaaS market. Our focus was not on the actual prices for specific resource types, but on the pricing schemes and mechanisms that are applied. For the study, we initially determined a set of 48 different IaaS providers using Google, based on common search terms such as "cloud", "cloud computing", "IaaS", and "provider".

For each provider, we identified and stored any artifacts that contained statements on pricing, such as Web pages or terms of service. It should be noted that our study focused on publicly available pricing information; hence, providers may offer different pricing schemes as part of bilateral negotiations with (major) customers.

An overview of all considered providers, along with their online addresses, can be found in Table 3 in the annex. Since our sample includes a large number of providers – both major players and small-and-medium-sized companies – we believe that it constitutes a representative picture of the IaaS market.

Nevertheless, limitations may arise from our previously described search procedure, which was based on Google: First, Google's index may be incomplete, i.e., certain providers may not be (prominently) listed; second, our search terms may be inadequate to identify all providers of interest.

Figure 1 shows the pricing mechanisms that were found among the considered providers. As can be seen, pay-as-you-go pricing is the dominant scheme and used by essentially all providers in our sample. However, subscription and freemium models are also widely applied, usually as a complement to pay-as-you-go pricing. A prominent example for this situation is Amazon Web Services' Elastic Compute Cloud, which offers a freemium-style *Free Tier*, pay-as-you-go *On-Demand Instances*, subscription-based *Reserved Instances*, and auction-based *Spot Instances*. Interestingly, Amazon is also the only provider in our sample to apply an interactive pricing scheme, i.e., auctioning. However, as Agmon Ben-Yehuda et al. (2011) point out in their work, that system is very likely not market-driven, indicating a low interest by consumers in auctioning schemes for IaaS resources.

Based on the previous results, we further examined the *commitment periods* for each distinct offer. By commitment period, we refer to the minimum period of time for which a user will be billed when a specific provider and pricing model is chosen. For example, in the case of Amazon Web Services' On-Demand Instances, a minimum period of one hour will be charged, regardless if the user terminates a VM instance prior to that period. In contrast, with Reserved Instances, a user will have to make a commitment for either one or three years and pay a corresponding fixed upfront fee, which subsequently results in lower variable operating costs per hour.

The results of this second part of our empirical study are provided in Figure 2. As can be seen, in conjunction with a pay-as-you-go pricing scheme, most IaaS providers seem to follow the example of Amazon Web Services, arguably of the pioneers in the cloud market, which uses a one-hour commitment period for its On-Demand Instances. However, a small number of providers also offer more fine-granular commitment periods in the order of magnitude of minutes or even seconds. Such shorter periods may be advantageous to certain user groups when resources are only leased for very brief time periods, e.g., in order to handle burst loads.

In contrast, many providers also use longer commitment periods in the order of magnitude of months or years, mostly in conjunction with subscription models. As the previously mentioned example of Amazon Web Services' Reserved Instances demonstrates, such models may be advantageous to a user if he/she continuously requires und actually exploits resources. However, it also contradicts the prevalent notion of high elasticity that is commonly associated with cloud computing (Mell and Grance, 2011), because costs will also accrue if instances are *not* actively used by the consumer.

In summary, concerning the third research question, we find that pay-as-you-go and subscription models are the pre-dominant pricing scheme in the IaaS market today. Thus, the empirical evidence largely supports the consensual literature view on cloud pricing that has been identified in the second section of this paper. However, due to the prevalence of commitment periods – most commonly in the order of magnitude of hours with pay-as-you-go models and months for subscription-based models –, pricing does not scale perfectly linear with the actual resource usage.

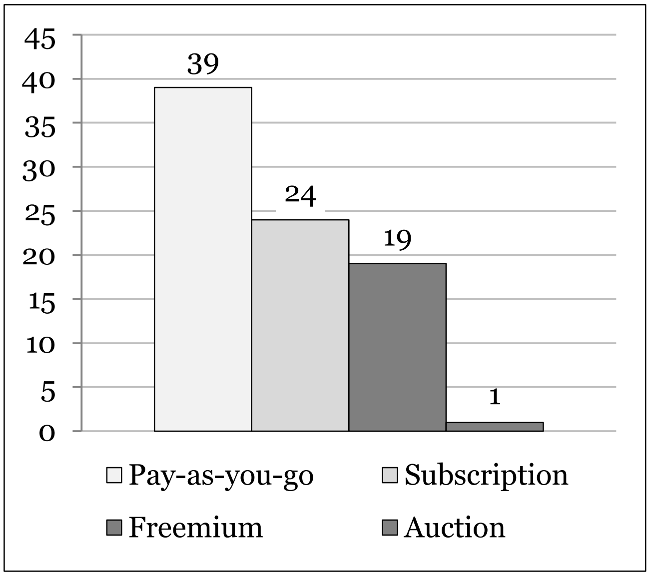
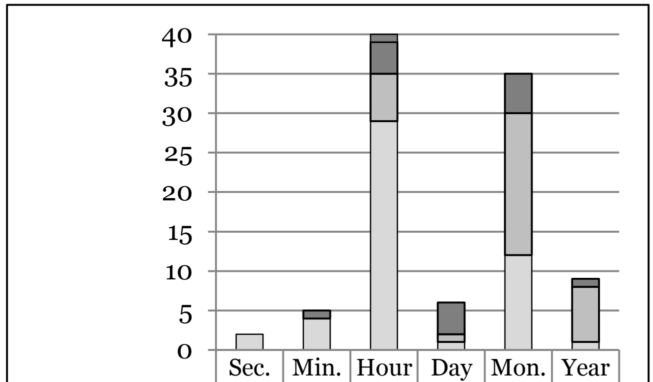


Figure 1: Applied pricing mechanisms among the considered IaaS providers (sample size n = 48; multiple options may apply for a single provider)



	Sec.	Min.	Hour	Day	Mon.	Year
Auction	0	0	1	0	0	0
Freemium	0	1	4	4	5	1
Subscription	0	0	6	1	18	7
Pay-as-you-go	2	4	29	1	12	1

Figure 2: Minimum commitment periods by order of magnitude across all pricing mechanisms among the considered IaaS providers (sample size n = 48; multiple options may apply for a single provider)

Conclusions

Cloud computing has revived the decade-old vision of providing IT resources in a utility-like, flexible fashion. With the growing maturity of the cloud market and the increasing standardization of products – specifically in the Infrastructure as a Service domain – lock-in effects diminish, and adequate pricing becomes a crucial success factor for cloud providers.

In this work, we examined three different aspects of pricing in infrastructure clouds: First, we examined the scientific perspective, based on a literature review. Second, we analytically assessed a set of popular pricing schemes with respect to their pros and cons when applied in the IaaS market. Third, we empirically examined the relevance of these pricing mechanisms, based on a sample of 48 IaaS providers.

Our results indicate that cloud computing is generally associated with a pay-as-you-go scheme in the current literature. Yet, our analytical study indicates that other, interactive pricing schemes – such as auctions – may be more advantageous from the standpoint of a cloud provider in practice, since they permit to differentiate prices between customers and more effectively skim the respective willingness to pay. However, such schemes are also more complex to appropriately design and market. Lastly, our empirical study has revealed that non-interactive pricing schemes – namely, pay-as-you-go and subscription – are the most widespread mechanisms in practice today. In this respect, our findings partially confirm the prevalent literature view on pricing in cloud computing.

However, based on our empirical study, we believe that cloud computing – at least as far as IaaS is concerned – should be seen as a model that permits access to a pool of compute capacity not only based on pay-as-you-go pricing schemes, but also based on subscription schemes. In this respect, cloud computing bears more resemblance with traditional Web server leasing than is conveyed by the established literature view. In addition, our research has demonstrated that interactive pricing only accounts for a minority of the market, even though such pricing mechanisms offer potential advantages, most notably the ability to more effectively skim consumers' willingness to pay.

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Annex

Table 3: List of IaaS providers considered in the empirical study

IaaS Provider Name	Online Address
Amazon AWS	http://aws.amazon.com/
AT&T	https://www.synaptic.att.com/
Atlantic	http://www.atlantic.net/cloud-hosting/
Bitrefinery	http://bitrefinery.com/
Cartika	http://www.cartika.com/
Cloud Provider	http://www.cloudprovider.net/
CloudSigma	http://www.cloudsigma.com/
DomainFactory	http://www.df.eu/
Elastichosts	http://www.elastichosts.com/

Exoscale	http://www.exoscale.ch/
Flexiscale	http://www.flexiscale.com/
Fujitsu	http://welcome.globalcloud.global.fujitsu.com/
Gandi	https://www.gandi.net/hosting/iaas
Gigenet	https://gigenet.com/cloud-servers/
GoGrid	https://www.gogrid.com/products/cloud-servers
Google	https://cloud.google.com/products/compute-engine/
HP Cloud	http://www.hpcloud.com/
Iland Internet Solutions	http://www.iland.com/
Incloudibly	https://incloudibly.com/en/cloud
Internap	http://www.internap.com
Itenos	http://www.itenos.de/
Joyent	http://www.joyent.com/products/compute-service/
Leaseweb	http://www.leaseweb.com/en/cloud-hosting/
LieCloud	http://www.liecloud.com
Linode	https://www.linode.com/
Logicworks	https://cloud.logicworks.net/
Lufthansa Systems	https://cloud.lhsystems.com/
Lunacloud	http://www.lunacloud.com/en/cloud-server
M5 Cloud Hosting	http://www.m5cloud.com/
MK Cloud	https://www.mk.de/
Nephoscale	http://nephoscale.com/cloud-servers/
OmniNet	http://www.omninet.co.nz/cloud-services/cloud-servers
OpSource	http://www.opsource.net/Services/Cloud-Hosting/Cloud-Servers
Peer1Hosting	http://www.peer1hosting.co.uk/cloud-hosting/
Poundhost	http://www.poundhost.com/cloud-servers
Profitbricks	http://www.profitbricks.de/
Rackspace	http://www.rackspace.com/
Rootaxcess	http://www.rootaxcess.com/cloud-server
Savvisdirect	http://www.savvisdirect.com/cloud-servers/
Servermule	http://www.servermule.com.au/
Softlayer	http://www.softlayer.com/cloudlayer/computing
Storm	https://www.stormondemand.com/servers/
Strato	https://www.strato-pro.com/ger/server-cloud/
Terremark	http://vcloudexpress.terremark.com/
vServerCenter	http://www.vservercenter.com/
Windows Azure	http://www.windowsazure.com/
Zettagrid	https://www.zettagrid.com/services/cloud-servers/
Zunicore	https://www.zunicore.com/