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Ph.D DISSERTATION

Analysis of Pricing Strategies of Infrastructure as a Service
(IaaS)

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PHD THESIS

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Dedication

This work is dedicated to Christina and Michalis.
You have made me stronger, better and more fulfilled that I could have ever imagined.

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Contents

List of Figures

List of Tables

Abstract

Cloud computing is one of the technologies that has met exponential growth and despite the fact that it has matured and has entered its second decade, there is still an increasing interest in cloud industry. PaaS, IaaS and SaaS models compose cloud environment and have met vigorous growth. More accurately, the IaaS model records the highest rates of growth and the number of providers that offer IaaS services is constantly increasing. Popular companies, such as Amazon and Microsoft, have already entered the cloud market and have established themselves as regulators in the market of cloud infrastructure. Additionally, IaaS services are turning to be a fundamental financial saver for businesses that wish to enjoy higher computational speeds and efficiency for less money and energy. As a result, an increasing number of organizations are moving their businesses to cloud environment for increased availability and scalability at lower costs.

Pricing a product is one of the most important decisions an organization makes. Price is a critical factor for both providers and users, since it influences the customer behavior, the loyalty to a provider and the provider's success. In addition, pricing schemes can be well-established tools for investments and guarantee that market-drive objective can be achieved. However, the pricing policies for IaaS services are complicated, which makes purchasing decision for users difficult. There is an essential differentiation among the providers when it comes to pricing process and there are no standards for the pricing policy. Therefore, it is difficult for users to understand each pricing policy, to compare and evaluate the price of an IaaS solution among a number of different offerings.

Given the essential role of pricing in the cloud computing industry, the current thesis describes IaaS services by defining and quantifying the functional and non-functional cloud attributes. It develops different approaches to price optimization and approaches the pricing of IaaS services by proposing well defined pricing models. The proposed pricing models adopt popular economic methods such as Hedonic Model, Structural Equation Model, PairWise Comparison framework and Data Envelopment Analysis. Both providers' and users' aspect is examined and the different aspects of pricing are highlighted. In cloud market the competition is fierce, thus the results of the thesis can be a powerful tool for providers to improve their services that do not keep up with users' priorities, understand what end users' value and take their preferences into consideration, expecting profitability improvement.

SUBJECT AREA: Cloud Computing

Keywords: Pricing models, Non-Functional Requirements, Efficiency, Data Envelopment Analysis, Strcutural Equation Model, Hedonic Method, PairWise Comparison framework.

Περίληψη

Η τεχνολογία του υπολογιστικού νέφους (Cloud Computing) έχει γνωρίσει τρομερή ανάπτυξη την τελευταία δεκαετία και παρόλο που η χρήση του υπολογιστικού νέφους έχει εδραιωθεί, το καινοτόμο αυτό επιχειρηματικό μοντέλο συνεχίζει να γνωρίζει μεγάλους ρυθμούς ανάπτυξης. Τα μοντέλα που συνθέτουν το υπολογιστικό νέφος είναι η Υποδομή ως υπηρεσία (IaaS), Υπηρεσίες Πλατφόρμας (PaaS) και οι υπηρεσίες Λογισμικού (SaaS) και γνωρίζουν μεγάλη ανάπτυξη, όμως οι IaaS υπηρεσίες ξεχωρίζουν για τον μεγαλύτερο ρυθμό ανάπτυξης. Ο αριθμός των παρόχων που προσφέρουν IaaS υπηρεσίες συνεχώς αυξάνεται και εταιρείες με εδραιωμένη θέση στην IT αγορά π.χ Amazon, Microsoft, IBM προσφέρουν IaaS υπηρεσίες με σκοπό την αύξηση των κερδών τους.

Ο αριθμός των επιχειρήσεων που χρησιμοποιούν IaaS υπηρεσίες συνεχώς αυξάνεται και περισσότεροι χρήστες υιοθετούν υπηρεσίες του υπολογιστικού νέφους, επιλέγοντας τη βέλτιστη λύση που καλύπτει τις ανάγκες τους. Όμως η πληθώρα ισοδύναμων IaaS υπηρεσιών σε διαφορετικές τιμές προκαλεί σύγχυση στους χρήστες οι οποίοι καλούνται να επιλέξουν την υπηρεσία που τους ταιριάζει καλύτερα με τα κριτήρια τους αλλά και με τα χρήματα που έχουν να διαθέσουν.

Οι πάμπολλες IaaS υπηρεσίες σε διαφορετικές τιμές και η έλλειψη τυποποίησης των τιμολογιακών πολιτικών των παρόχων συγχέει τους χρήστες και δημιουργεί πολλά προβλήματα στην λήψη αποφάσεων. Προς αυτήν την κατεύθυνση, η τρέχουσα διατριβή ορίζει τις IaaS υπηρεσίες αξιοποιώντας λειτουργικά και μη λειτουργικά χαρακτηριστικά. Επιπλέον εξετάζει, μελετά και προτείνει μοντέλα τιμολόγησης, βασισμένα σε γνωστές οικονομικές και στατιστικές μεθόδους. Εξετάζεται και μελετάται η άποψη του χρήστη αλλά και του παρόχου, αναδεικνύοντας τα προτεινόμενα μοντέλα τιμολόγησης της διατριβής τα οποία βασίζονται στα Ηδονικά Μοντέλα(Hedonic Methods) , στη μέθοδο PairWise, στην Περιβάλλουσα Ανάλυση Δεδομένων (Data Envelopment Analysis) και στα Μοντέλα Δομικών Εξισώσεων (Structural Equation Model)

ΛΕΞΕΙΣ -ΚΛΕΙΔΙΑ: Μοντέλα Τιμολόγησης, Μη λειτουργικές απαιτήσεις, Λειτουργικές Απαιτήσεις, Αποδοτικότητα, Περιβάλλουσα Ανάλυση Δεδομένων, Μοντέλα Δομικών Εξισώσεων, Μέθοδος PairWise

ΘΕΜΑΤΙΚΕΣ ΠΕΡΙΟΧΕΣ: Υπολογιστικό νέφος

Συνοπτική Παρουσίαση της Διδακτορικής Διατριβή

Το υπολογιστικό νέφος (cloud computing) είναι η διάθεση υπολογιστικών πόρων μέσω διαδικτύου(π.χ. servers, apps κλπ), από κεντρικά συστήματα που βρίσκονται απομακρυσμένα από τον τελικό χρήστη, τα οποία τον εξυπηρετούν αυτοματοποιώντας διαδικασίες, παρέχοντας ευκολίες και ευελιξία σύνδεσης (Mell and Grance, 2011). Η τεχνολογία του cloud computing προσφέρει ευελιξία σε επιχειρήσεις με αυξανόμενες ή κυμαινόμενες απαιτήσεις, μειώνει το υψηλό κόστος του υλικού (hardware) και προωθεί την ανταγωνιστικότητα. Τα μοντέλα που συνθέτουν το υπολογιστικό νέφος, όπως παρουσιάζονται είναι:

- **Software-as-a-Service (SaaS)**: Αποδεσμεύει το χρήστη από την εγκατάσταση και διαχείριση του λογισμικού και του προσφέρει μία μεγάλη γκάμα εφαρμογών, από τις πιο κοινές, όπως τις εφαρμογές γραφείου, ως τις πιο εξειδικευμένες.
- **Platform-as-a-Service (PaaS)**: Παρέχει ό,τι χρειάζεται μία εφαρμογή για να εκτελεστεί, δηλαδή το υλικό, το λειτουργικό σύστημα, η βάση δεδομένων, οι εξυπηρετητές και το λογισμικό.
- **Infrastructure-as-a-Service (IaaS)**: Εικονικές υπολογιστικές μηχανές, εξυπηρετητές, αποθηκευτικά μέσα και γενικά μία πλήρης υπολογιστική υποδομή.

Η παρούσα διατριβή εξετάζει και μελετά τις IaaS υπηρεσίες, οι οποίες είναι οπλές-βασικές υλικές συσκευές (raw υπολογιστές) όπως είναι: Εικονικοί υπολογιστές (**V**irtual **M**achines), Servers, συσκευές αποθήκευσης. Οι υπηρεσίες IaaS προσφέρουν στους χρήστες μικρότερο κόστος υλικού (hardware), σύγχρονος εξοπλισμός ο οποίος μπορεί να ανανεώνεται όσο συχνά ο χρήστης επιθυμεί και μπορεί να το υποστηρίξει οικονομικά.

Οι IaaS υπηρεσίες έχουν τον μεγαλύτερο ρυθμό ανάπτυξης συγκριτικά με τις IaaS και PaaS υπηρεσίες(Katie Costello, 2019). Επομένως μεγάλες IT επιχειρήσεις π.χ Amazon, Google προσφέρουν υπηρεσίες IaaS υπηρεσίες, στοχεύοντας σε αύξηση των κερδών τους και ο ανταγωνισμός μεταξύ των παρόχων είναι έντονος. Επιπλέον ο αριθμός χρηστών IaaS αυξάνεται συνεχώς καθώς οι χρήστες στοχεύουν να αποκτήσουν τη βέλτιστη υπηρεσία στην καλύτερη τιμή.

Η τιμή συνδέει τους παρόχους με τους χρήστες κ αποτελεί καθοριστικό παράγοντα υιοθέτησης ή μη των cloud υπηρεσιών. Ο ορισμός της τιμής των IaaS υπηρεσιών επιτρέπει στους παρόχους να εξετάσουν τις τιμολογιακές πολιτικές ανταγωνιστών, να μελετήσουν τη σχέση της αποδοτικότητας των IaaS υπηρεσιών τους σε σχέση με την τιμή (value for money) και να βελτιώσουν τις υπηρεσίες τους ικανοποιώντας τις απαιτήσεις των χρηστών, αυξάνοντάς το μερίδιο τους στην αγορά. Όμως οι χρήστες δυσκολεύονται να συγκρίνουν τις IaaS υπηρεσίες από διαφορετικούς παρόχους αφού οι πάροχοι προσφέρουν ισοδύναμες υπηρεσίες σε διαφορετικές τιμές. Οι διαφορές στην τιμολόγηση των IaaS υπηρεσιών δυσκολεύουν τους χρήστες να κατανοήσουν τον τρόπο τιμολόγησης των παρόχων, αφού δεν υπάρχει κάποιο μοτίβο διαμόρφωσης της τελικής τιμής.

Η παρούσα διατριβή, λαμβάνοντας υπόψη το θολό τοπίο της τιμολόγησης των IaaS υπηρεσιών, μελετά την τιμολόγηση των IaaS υπηρεσιών από την οπτική των παρόχων και των χρηστών. Υλοποιεί τιμολογιακά μοντέλα και υπολογίζει σε τι βαθμό τα χαρακτηριστικά και οι απαιτήσεις(requirements) των IaaS υπηρεσιών συμμετέχουν στη διαμόρφωση της τελικής τιμής. Στο πλαίσιο της διατριβής, οι υπηρεσίες IaaS ορίστηκαν από τις Λειτουργικές Απαιτήσεις (Functional Requirements) και τις Μη-λειτουργικές απαιτήσεις (Non- Functional Requirements). Τα Λειτουργικά Χαρακτηριστικά (Functional Attributes) περιγράφουν τι πρέπει να κάνει μια IaaS υπηρεσία, όπως η *Υπολογιστική ισχύ, Μνήμη και ο Αποθηκευτικός χώρος*. Τα Μη λειτουργικά Χαρακτηριστικά (Non-Functional Attributes) περιγράφουν το πώς (ή πόσο καλά) υποστηρίζονται οι λειτουργικές απαιτήσεις και μπορούν να θεωρηθούν ως περιορισμοί που ορίζουν τους τρόπους με τους οποίους θα μπορούσαν να υλοποιηθούν οι λειτουργικές απαιτήσεις, παράδειγμα το χαρακτηριστικό *Burstable CPU.*

Τα προτεινόμενα τιμολογιακά μοντέλα βασίστηκαν σε στατιστικές και οικονομικές μεθόδους. Για την μελέτη της οπτικής του παρόχου, χρησιμοποιήθηκαν τα Ηδονικά μοντέλα (Hedonic Models, Περιβάλλουσα Ανάλυση Δεδομένων, **D**ata **E**nvelopment **A**nalysis (DEA), Μοντέλα Δομικών Εξισώσεων, **S**tructural **E**quation **M**odel (SEM). Ενώ η μελέτη της οπτικής του χρήστη βασίστηκε στη μέθοδο **P**air**W**ise **C**omparison (PWC). Για την υλοποίηση των προτεινόμενων τιμολογιακών μοντέλων συλλέχθηκαν δεδομένα από την πλατφόρμα σύγκρισης τιμής των IaaS υπηρεσιών Cloudorado, όπου ο χρήστης επιλέγει τα χαρακτηριστικά των IaaS υπηρεσιών με κριτήριο τις απαιτήσεις του αλλά και διαδικτυακό ερωτηματολόγιο συμπληρώθηκε από τους 20 χρήστες των IaaS υπηρεσιών.

Αρχικά η οπτική του παρόχου εξετάστηκε, κατασκευάζοντας και συγκρίνοντας δύο διαφορετικούς ηδονικούς δείκτες τιμών, όπου ο πρώτος περιλαμβάνει αποκλειστικά λειτουργικά χαρακτηριστικά ενώ ο δεύτερος δείκτης τιμών περιλαμβάνει λειτουργικά και μη λειτουργικά χαρακτηριστικά.(Mitropoulou, 2017, Mitropoulou et al., 2016, Mitropoulou et al., 2015). Η σύγκριση των δυο δεικτών αναδεικνύει το σημαντικό ρόλο των μη λειτουργικών χαρακτηριστικών στη διαμόρφωση της τελικής τιμής των IaaS υπηρεσιών.

Παρόλο που τα αποτελέσματα των ηδονικών μεθόδων επισημαίνουν τον καταλυτικό ρόλο των μη λειτουργικών χαρακτηριστικών διαμόρφωση της τελικής τιμής των IaaS υπηρεσιών, δεν παρουσιάστηκαν σαφή συμπεράσματα για την επίδραση των μη λειτουργικών απαιτήσεων στη διαμόρφωση της τελικής τιμής, βασιζόμενοι στην οπτική του παρόχου. Προς αυτήν την κατεύθυνση, στο πλαίσιο της διατριβής τα λειτουργικά και τα μη λειτουργικά χαρακτηριστικά, σύμφωνα με τη βιβλιογραφία(Glinz, 2007), ομαδοποιήθηκαν σε λειτουργικές και μη λειτουργικές απαιτήσεις/κατηγορίες, (Ασφάλεια, Διαθεσιμότητα, Ελαστικότητα, Χρηστικότητα και απόδοση) . Η επίδραση των λειτουργικών και μη λειτουργικών απαιτήσεων/κατηγοριών στον καθορισμό της τελικής τιμής υπολογίστηκε με τα Μοντέλα Δομικών Εξισώσεων (Structural Equation Model) (Filiopoulou et al., 2019). Τα αποτελέσματα του μοντέλου παρουσιάζουν ότι παρόλο που η λειτουργική απαίτηση κατέχει πρωταγωνιστικό ρόλο στη διαμόρφωση της τελικής τιμής, οι μη λειτουργικές απαιτήσεις συμμετέχουν σημαντικά στη διαδικασία της τιμολόγησης.

Η τιμολόγηση των IaaS υπηρεσιών είναι σημαντικά συνδεδεμένη με την αποδοτικότητα, δηλαδή την σχέση τιμής-αποτελεσματικότητας. Οι χρήστες αγοράζουν IaaS από τους παρόχους αλλά πόσο αποτελεσματικές είναι οι υπηρεσίες αυτές σε σχέση με την τιμή που έχει οριστεί. Επομένως χρησιμοποιώντας την Περιβάλλουσα Ανάλυση Δεδομένων, **D**ata **E**nvelopment **A**nalysis (DEA), εξετάστηκε κατά πόσο τα μη λειτουργικά χαρακτηριστικά συνεισφέρουν στην αποδοτικότητα των IaaS υπηρεσιών αλλά επίσης επισημάνθηκε ότι η τιμή δεν μπορεί είναι το μοναδικό κριτήριο για την αγορά υπηρεσιών (Filiopoulou et al., 2018).

Η διατριβή μελέτησε και την οπτική του χρήστη η οποία σπάνια έχει αναδειχθεί στην σχετική βιβλιογραφία. Γνωρίζοντας ότι ο χρήστης αναζητά την καλύτερη υπηρεσία στην καλύτερη τιμή, οι απαιτήσεις και οι προτεραιότητες του χρήστη επισημάνθηκαν. Η μέθοδος PairWise Comparison υιοθετήθηκε για να αναδείξει τις απαιτήσεις των χρηστών, η οποία υπολογίζει το βάρος (weight) που επισημαίνει πόσο σημαντικό ή όχι θεωρεί ο χρήστης ένα functional/non-functional requirement. Τα αποτελέσματα της μεθόδου προβάλλουν ότι και οι χρήστες θεωρούν τη λειτουργικη απαίτηση σημαντική στη διαμόρφωση της τιμής αλλά οι μη λειτουργικές απαιτήσεις συμμετέχουν με σημαντική συνεισφορά στη διαμόρφωση των IaaS υπηρεσιών. (Filiopoulou et al., 2019).

Συμπερασματικά, αναδείχθηκε ότι η συνδρομή (subscription) και τα λειτουργικά χαρακτηριστικά κατέχουν πρωταγωνιστικό ρόλο στην τιμολόγηση. Επιπλέον επιβεβαιώθηκε ο σημαντικός ρόλος των ποιοτικών χαρακτηριστικών στη διαμόρφωση της τελικής τιμής αλλα και στη βελτίωση της αποδοτικότητας των IaaS υπηρεσιών. Επίσης αναδείχθηκε η οπτική του χρήστη σε σχέση με την τιμολόγηση των υπηρεσιών. Η συνεισφορά της συγκεκριμένης ερευνητικής διατριβής βοηθά τους πάροχους (Providers) οι οποίοι βασιζόμενοι στα αποτελέσματα μπορούν να βελτιώσουν τις υπηρεσιών τους και να αυξήσουν τα κέρδη τους. Επιπλεόν οι χρήστες (Users) επωφελούνται από βελτιωμένες υπηρεσίες αλλά πλέον κατανοούν τις τιμολογιακές πολιτικές των παρόχων. Τα προτεινόμενα τιμολογιακά μοντέλα μπορούν να αποτελέσουν οδηγό στους ερευνητές οι οποίοι μπορούν να τα αναβαθμίσουν και τα επεκτείνουν στις άλλες υπηρεσίες του υπολογιστικού νέφους. Ως μελλοντικές κατευθύνσεις μπορούν να θεωρηθούν η παρακολούθηση αλλαγών των μοντέλων τιμολόγησης (π.χ κατασκευή δείκτη τιμών), η επέκταση των μοντέλων τιμολόγησης σε PaaS και SaaS υπηρεσίες και η μελέτη και επέκταση του Cloud Broker.

Chapter 1 Introduction

1.1 General

Cloud computing is one of the technologies that has met exponential growth and despite the fact that it has matured and has entered its second decade, there is still an increasing interest in cloud industry. In today's hypercompetitive markets, cloud environment has fundamentally changed the way companies manage evey aspect of their business, from sales and marketing to logistics, risk management and much more.

Cloud computing is a general purpose technology that has moved computing and data away from desktop and portable PCs into large data centers. It is named "cloud" because everything is stored remotely and delivered via web-based connections. It is an important part of contemporary information technology, since cloud services keep businesses and their information connected at all times. Nothing is stored on the local hard disk and data are accessible from any location, using any device and at any time. It is quite complicated for users to realize that despite being held in the "cloud", their data still need to be physically stored on a device, somewhere over the internet. Therefore, companies offer cloud services by operating large facilities with servers, known as cloud datacenters. Cloud datacenters deliver virtual machines (VMs) to end users and power services, whereas end users use these facilities to store data, create virtual networks and develop applications. A massive number of businesses have migrated to the cloud, since it has greatly simplified the capacity provisioning processes.Cloud Computing is divided into three service categories: Infrastructure as a Service (IaaS), Platfrom as a Service and Software as a Service (SaaS). Infrastructure as a Service refers to the renting of computer hardware (servers, networking technology, storage and data center space) instead of buying and installing it in a proprietary datacenter. Platform as a Service (PaaS) is an integrated cloud-based computing environment that supports the development, running and management of applications. Software as a Service is a software distribition model in which a third-party provider hosts applications and makes them available to customer over the Internet.

According to Gartner Inc, Software as a Service (SaaS) is the largest market segment and Infrastructure as a Service (IaaS) is the second-largest market segment. However,IaaS has been recording the highest rates of growth (Katie Costello, 2019). Analytically, IaaS service is expected to grow up 24% and it is estimated to reach $74.1billion. On the contrary, SaaS service is expected to grow 15%, reaching $151.1 billion and PaaS service will develop 20% reaching $58 billion.

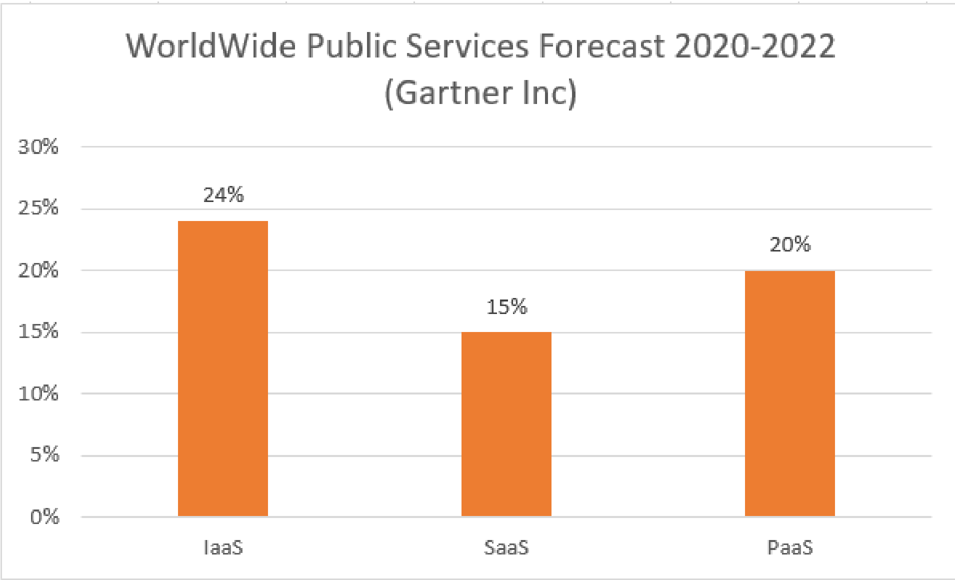

Figure 1 Worldwide Public Service Forecast (2020-2022)

The continual growth of the IaaS model has increased the number of the providers that offer the corresponding services. Companies such as Amazon, Google Microsoft Azure have already entered the cloud market and have established themselves as regulators in the market of cloud infrastructure. Providers offer IaaS services at a reasonable price, aiming to be accessible to the potential users, independently of their budget. The imperative demand for qualitative and financially optimal cloud services has driven a fierce competition among cloud providers that aim to increase their grip on the market and maximize their revenues. Providers offer solutions that fulfill users requirements combined with affordable prices, since price is the determinant factor that drives users to cloud adoption.

In addition, cloud computing is turning to be a fundamental financial saver for businesses that wish to enjoy higher computional speeds and efficiency for less money and energy. As a result, an increasing number of organisations are moving their businesses to cloud environment for increased availability and scalability at lower costs. Businesses replace their propiertary IT equipment with IaaS services that are cheaper and more reliable for their needs.

Unfornunately, the pricing policies for IaaS services are complicated, which makes purchasing decision for users difficult. There is an essential differentiation among the providers, when it comes to pricing process and there are no standards for the pricing policy. Therefore, it is difficult for users to understand each pricing policy, to compare and evaluate the price of an IaaS solution among a number of different offering.

Pricing of a service is a critical factor for providers, since it highly influences the customer behavior, the loyalty to a provider and the provider's success. Pricing schemes can be well-established tools for investments and guarantee that market-drive objective can be achieved. A pricing model takes into consideration manufacturing and mainatance costs, market competition and the way the customer values the offered cloud service. The pricing of a IaaS service is a top management puzzle, often solved by examining and analyzing the factors that define the pricing mechanism. Towards this direction this thesis is devoted to the pricing mechanism of cloud computing, presenting a twofold approach that introduces and analyzes both providers' and users' aspects. Pricing models help providers to maximize their revenues while on the same time they guide users to obtain qualitative cloud solutions at affordable prices.Unfortunately, cloud pricing policies are complicated, which makes purchasing decision for users difficult and the comparison across providers a challenge as well. Therefore, this thesis proposes suitable and transparent pricing models, and calculates the impact of cloud attributes on the determination of cloud price highlighting both users' and providers' aspects.Apart from the functional, the non-functional cloud attributes have been also been considered and quantified, leading to accurate conclusions about the shaping of the cloud price.

In addition, suitable cloud pricing models promote cost-effectiveness by assisting users to select not only the optimal but also the most cost-effective cloud solution. Numerous equivalent cloud solutions from different cloud providers are evaluated by applying a well defined pricing strategy. End users can expand their IT infrastructure without upfront capital investment and use cost effective cloud solutions. Cost effective solutions offer the maximum service in a reasonable price. Cloud providers can increase their revenues, by improving the economics of their clients and manage usage so clients pay as little as possible for their services

Given the essential role of pricing in the cloud computing industry, the current thesis constitutes an analysis that approaches the pricing of cloud computing and proposes well defined pricing models. The proposed pricing models capture both providers' and users' aspect and have adopted popular economic methods that examine the different aspects of pricing. It can be a powerful tool for providers, since the users' aspect is presented, therefore the providers can improve their services, based on users' priorities and perception. In addition, the proposed models constitute a remarkable decision-making tool, evaluating cloud services in terms of their efficiency.

1.2 Objectives

The continuous growth of IaaS model has favored the cloud providers and the businesses that have moved to cloud enviroment. However, the large variety of equivalent IaaS services at different prices, has puzzled the cloud market. Each cloud provider apply different pricing policy and it is complicated to examine and analyze the pricing policies of its competitors. At the same time, it is quite diffucult for users to compare and evaluate the offered IaaS solution, in order to choose the most cost-effective service.

In that context, the following goals of the current thesis were considered:

- describe the cloud computing main services and deployment models,
- present the benefits of cloud computing by proposing a cost assessment method that calculates cost after cloud adoption,
- examine the capital (CapEx) and operational expenditures (OpEx) of a business and its shift to the cloud,
- examine the impact of cloud attributes on pricing,
- examine cloud diffusion and acceptance on the market,
- analyze cloud efficiency and its relation to price.

Towards this direction, the following tasks have been completed:

a. Evaluation of the acceptance and diffusion of cloud technology across Europe. (Filiopoulou et al., Konstantinos et al., 2015)

b. Calculation of the Total Cost of Ownership for a business that owns proprietary equipment and its comparison with the TCO of business that migrates into the cloud. (Konstantinos et al., 2015)

c. Construction of a price Index for Infrastructure as a Service (IaaS) cloud computing services, based on the hedonic pricing method developing variations that consider both functional and non-functional attributes (Mitropoulou et al., 2016, Mitropoulou et al., 2015, Mitropoulou et al., 2017).

d. Development of a nonparametric model that estimates relative efficiency of cloud services and introduces cost-effective cloud solutions, by applying Data Envelopment Analysis (DEA) (Filiopoulou et al., 2018).

e. Estimation of the of the key cloud requirements impact on the pricing policy of cloud services, based on Structural Equation Modeling (SEM), for pointing out users' aspect and Pairwise Comparisons (PWC), for the providers' perspective.

f. Review of cloud brokering pricing methods, aiming to highlight the crucial role of broker in cloud computing economics (Filiopoulou et al., 2016).

1.3 Overview

The current pricing analysis focuses on IaaS services, since the IaaS model is considered to be the most straightforward and suitable cloud service for the scope of this thesis.

IaaS services are defined by functional attributes, including compute power, memory and storage but also include non-functional attributes that describe how the services should operate. Each provider develops and adopts different pricing model for its offered services, indicating that different factors are taking into consideration for price determination . However, numerous and equivalent cloud services and different pricing mechanisms confuse end users through the evaluation of the different pricing polices.

Therefore, the current thesis examines pricing policies, presenting and analyzing the way cloud providers assess their services, together with the way cloud users financially evaluate and perceive these services. Towards this direction, popular economic and statistical methods have been applied on IaaS services, pointing out the factors that contribute to the shaping of the price. Furthermore, cloud cost-effectiveness has been examined by evaluating cloud solutions as efficient that offer the maximum resources at a reasonable price. Cloud attributes that promote efficiency are also highlighted..

Focusing on providers' standpoint the economic methods that are used for the development of the proposed pricing model are:

- Hedonic Models
- Data Envelopment Analysis
- Structural Equation Model

Price is the main factor that drives users to choose the optimal cloud solution that fulfills their need. Therefore, a decision making method, known as PairWise Comparison (PWC), has been adopted, which evaluates cloud attributes by examing their contribution in the shaping of the final price

In addition, the current pricing proposal also examines the important and unquestionable role of cloud broker in cloud environment. The numerous cloud services, the various and confused pricing policies make it difficult for the users to choose the most suitable cloud solution. Therefore, the cloud broker acts as an intermediary between users and providers, assisting the former to choose the services that meet their requirements and the latter to schedule resources and apply effective pricing schemes. Pricing schemes directly related with brokerage services are reviewed, highlighting the economic context of broker.

Figure 2 presents an overview of the adopted pricing analysis.

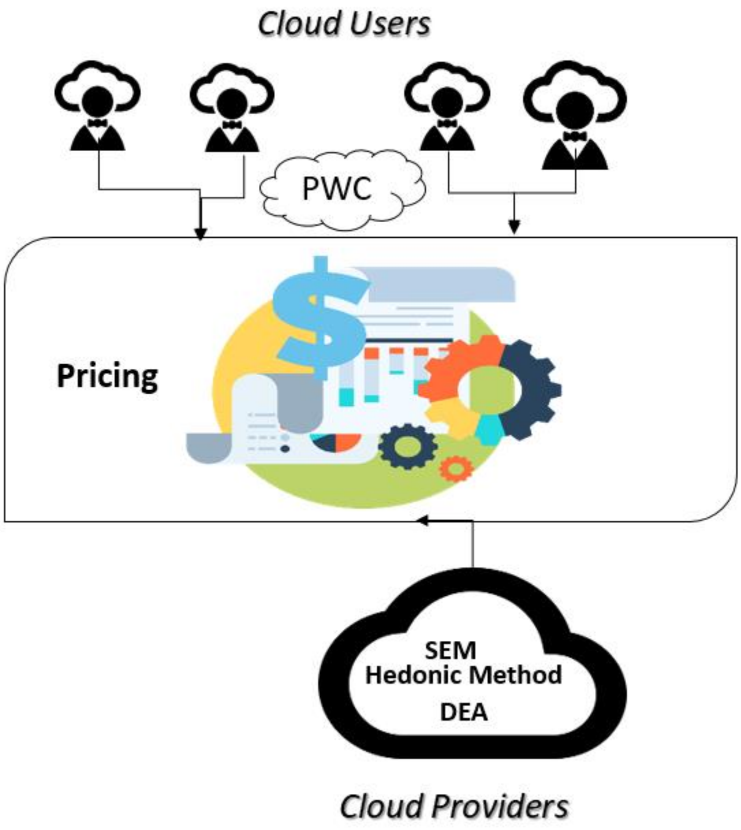

Figure 2 Phd Overview

1.4 Structure

The structure of the present thesis is as follows: Chapter 2 presents the background of cloud computing by giving the definition and describing the offered services and deployments models of cloud computing. Chapter 3 presents the economic aspects of cloud computing by outlining the economic benefits of the cloud and its diffusion into the market. In addition, capital and operational expenditures of a business are introduced and analyzed, presenting on the same time a case study that examines the adoption of cloud services from a startup business. Chapter 4 and Chapter 5 introduce pricing methodologies, from the standpoint of the cloud provider, based on the Hedonic Model and the Structural Equation Model methods. Chapter 6 adopts Data Envelopment Analysis and focuses on the efficiency of cloud services, calculating the efficiency of cloud services and examining the impact of functional and non-functional cloud attributes on efficiency. Chapter 7 examines the user perception of pricing, by adopting PairWise Comparison. Finally, Chapter 8 presents the conclusions of the thesis, along with directions for future work.

Chapter 2 Background of Cloud Computing

2.1 Outline

This chapter presents cloud technology by introducing the definition of cloud computing, the essential characteristics of cloud services and the cloud deployments models. Furthermore, the Cloud Brokerage Service is presented, since it is an efficient and cost effective service to leverage the benefits of the cloud.

2.2 Cloud Computing Business Model

Cloud computing has transformed Information and communications technology (ICT) and has fundamentally changed business operations. In order to effectivelly employ cloud technology, businesses must comprehend what exactly cloud computing is. According to the International Organization for Standardization (ISO) cloud computing is a paradigm for enabling network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on demand.(Siben). In addition the National Institute of Standards and Technology (NIST), USA, has also provided a definition of cloud computing and has also designated five essential characteristics, three service models, and four deployment models of cloud technology.

According to NIST, Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (Mell and Grance, 2011).

The essential characteristics that every cloud service should have are presented below and illustrated in Figure 3**Error! Reference source not found.** .

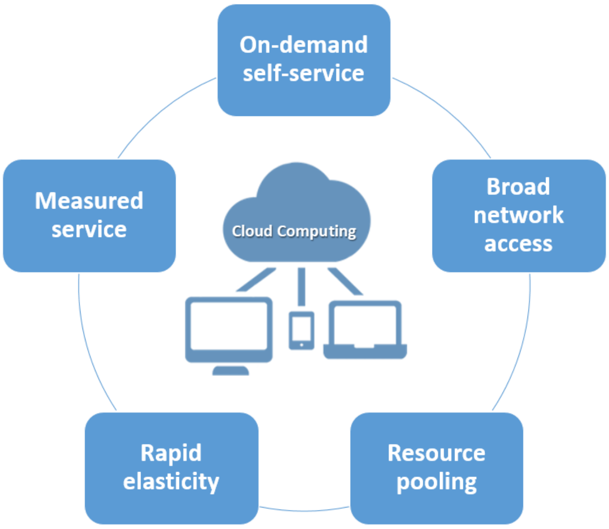

Figure 3 Essential Characteristics of Cloud Computing

On-demand self-service. It refers to the service provided by vendors that enables the provision of cloud resources on demand whenever they are required. It is a prime feature of most cloud offerings where the user can scale the required infrastructure up to a substantial level without disrupting the host operations. **Broad network access.** Capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, tablets, laptops, and workstations).

Resource pooling. The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. There is a sense of location independence in that the customer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state, or datacenter). Examples of resources include storage, processing, memory, and network bandwidth.

Rapid elasticity. Capabilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward commensurate with demand. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time.

Measured service. Cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported, providing transparency for both the provider and the consumer of the utilized service.(Mell and Grance, 2011)

According to NIST the cloud model is composed by three service models and four deployments models.

2.3. Deployment Models

A cloud deployment model represents a particular type of cloud environment, mainly distinguished by size, access and ownership(Armbrust et al., 2010). Four common cloud deployment models are presented below.

- **Private cloud.** The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed and operated by the organization, a third party, or some combination of them, and it may exist on or off premises. Community cloud. The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises.

- **Public cloud**. The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of them. Public cloud allows for scalability and resource sharing that would not otherwise be possible for a single organization to achieve.

- **Hybrid cloud**. The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds). Hybrid cloud services are powerful because they offer to businesses greater control over their private data. A business can store sensitive data on a private cloud and simultaneously leverage the robust computational resources of a managed public cloud.

Figure 4 graphically introduces cloud deployment models.

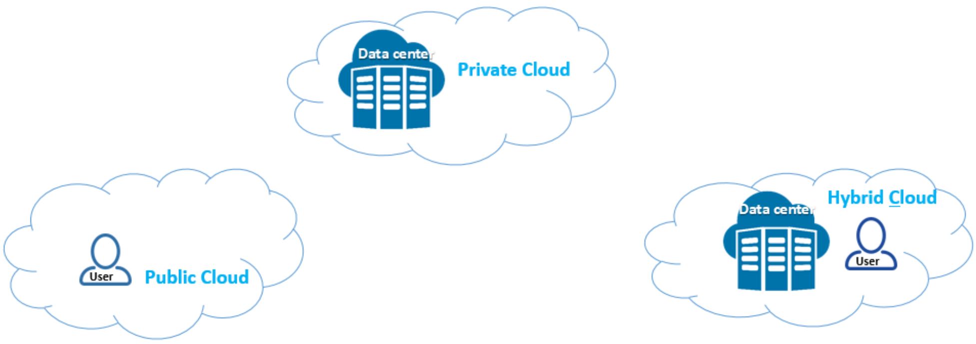

Figure 4 Cloud deployment models

2.4 Service Models

Cloud computing can probably fulfill any IT requirement, thus the classification of cloud service model is necessary in order to point out the role that a specific cloud service fulfills and how this service accomplishes its role. Therefore, three primary cloud computing service models are introduced.

- **Software as a Service (SaaS).** The capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g., web-based email), or a program interface. The consumer does not manage or control the underlying cloud infrastructure, including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

- **Platform as a Service (PaaS)**. The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications, created using programming languages, libraries, services and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage but has control over the deployed applications and possibly configuration settings for the application-hosting environment.
- **Infrastructure as a Service (IaaS).** It is the lowest –level cloud service paradigm. It describes the capability provided to the consumer for the provision of processing power, storage, networks and other fundamental computing resources, where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications and possibly limited control of select networking components (e.g., host firewalls).

Figure 5 depicts the services of the service models.

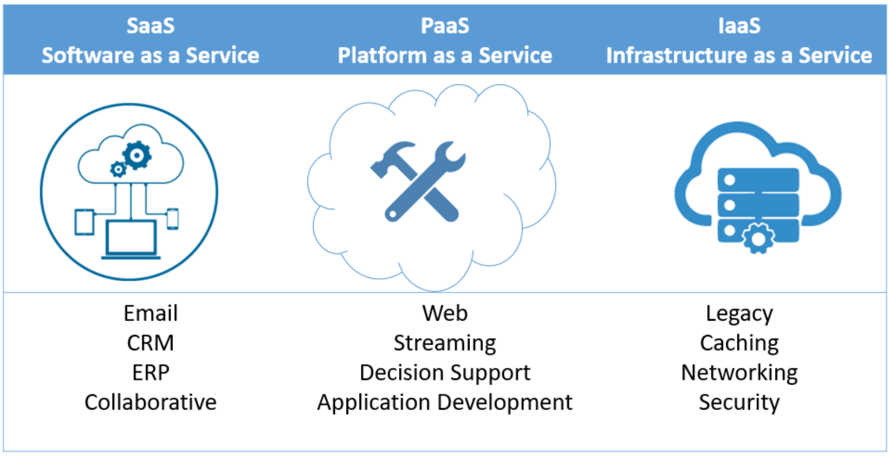

Figure 5 Services of the service models

In the context of this thesis the proposed pricing methods focus on IaaS services, since they correspond to the most straightforward service of the cloud. The IaaS delivery model has evolved traditional hosting by allowing users to the provision of computing resources in the form of virtualized machines (VMs), each with its own operating system (Brebner and Liu, 2010) running on shared physical servers and storage appliances. Virtualization supports cost savings and efficient use of resources.

IaaS services can be described by functional attributes, mainly the CPU type, the memory size and the storage capacity and non-functional features, such as storage encryption and the option of backup storage. The non-functional attributes of cloud services describe the qualitative aspect of cloud provision rather than specific technological requirements (Glinz, 2007). Cloud users mainly select services that fulfill their functional requirements and usually neglect qualitative features. At the same time, they struggle to obtain the best possible performance at a minimum cost. Figure 6 graphically illustrates the attributes of IaaS services cloud environment.

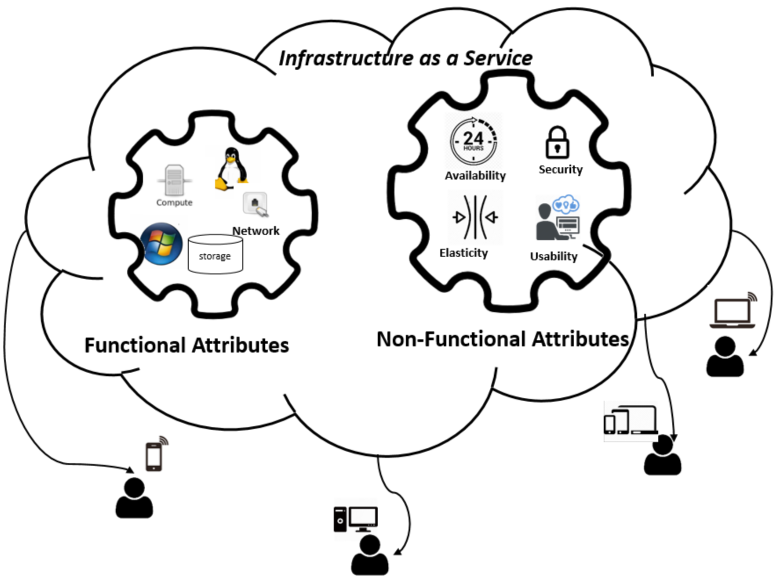

Figure 6 IaaS cloud services

2.5 Cloud Brokerage Services

Even though cloud has matured and has entered its second decade, the number of businesses that decide to migrate to cloud environment is constantly increasing. Cloud providers offer cloud services that fulfill users' requirements, aiming to increase their market share and their profitability but the numerous and equivalent cloud solutions confuse end users, who want to choose the most cost-effective solution. Therefore, cloud service brokerage (CBS) has dynamically entered the cloud industry and the global Cloud Service Brokerage market is expected to grow from USD 6,78 billion in 2018 to USD 15.03 billion by 2023, at a Compound Annual Growth Rate (CAGR)of 17,3% during the forecast period (Gartner) .

Cloud Service Brokerage (CSB) is an IT role and business model in which a company or other entity adds value to one or more (public or private) cloud services on behalf of one or more consumers(Gartner). Cloud brokerage services provides services in three categories:

1. **Intermediation**: A cloud broker provides value-added services, enhancing existing services by improving some of its capabilities. These services may include security management and reporting or supervision on pricing and billing. (Pritzker and Gallagher, 2013, Geetha et al., 2014).
2. **Aggregation**: A cloud broker can customize and combine multiple cloud services into one or more services. An aggregation service establishes the secure data movement between businesses and multiple cloud providers and includes data integration (Pritzker and Gallagher, 2013, Geetha et al., 2014).
3. **Arbitrage**: A cloud broker assists customers to select several cloud providers according to requirements, such as cost or performance. Service arbitrage is similar to service

A CSB can bundle all cloud services into a single bill, i.e. a customer can manage cloud services provider bills for the various IaaS, PaaS and SaaS by using CBS offer not only the best provider but also integrate disparate services across multiple hybrid approaches. Furthermore, it promotes the integration of the entire cloud ecosystem by connecting hardware (IBM, HP, Dell) and software industries (Microsoft, Citrix)with PaaS, IaaS, SaaS providers (Google, Salesforce, Amazon, and Rackspace_, (King, 2013).

Businesses, CBS and providers agree at a Service Level Agreement (SLA) that presents and specifies the details of the service, based on the requirements. The SLA is agreed by all parties; it determines details about the provided services and contains penalties for violating the expectations of all parties (Buyya et al., 2009). CBS manages cloud services and supports businesses by offering technical services, focusing on managing interoperability issues among providers (Pritzker and Gallagher, 2013) and can also acts as a single point of contact for support and SLA accountability across all your cloud service vendors. Figure 7 describes CBS.

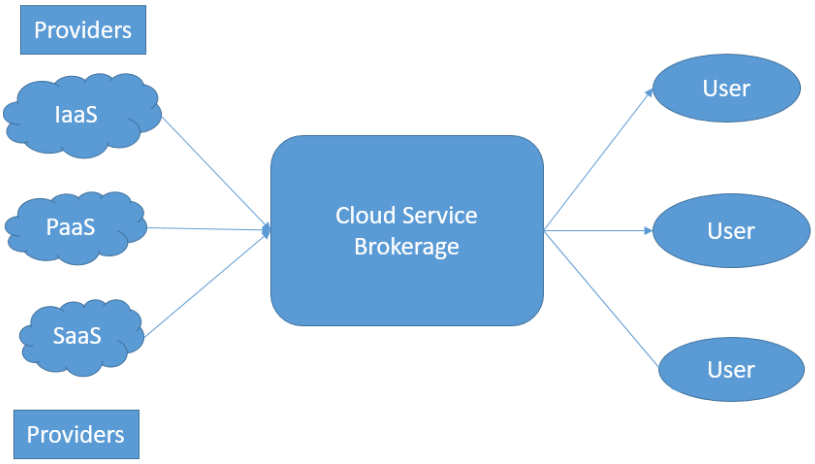

Figure 7 Cloud Brokerage Services

CBS model also provides budget guidance to businesses and assists them to adopt a cost effective solution by satisfying budget requirements. It usually achieves better discounts, reduces capital costs and accesses more information from providers (Geetha et al., 2014). Since cloud providers deliver many services it is almost impossible to manage each customer individually, therefore providers need the intermediate cloud broker in order to promote their services to the clients (Sampson, 2012).

Chapter 3 Economics of the cloud

3.1 Outline

The use of cloud computing appears to provide significant cost savings. Startup companies benefit from the advantages that cloud offers but also established companies decide to shift to cloud environment, improving their business environment. The focal point in any business is to decide where to spend money, therefore the financial advantages of cloud computing are presented and also a case study that highlights the beneficial role of cloud industry is introduced. Furthermore the diffusion of the cloud in European area is presented.

3.2 Benefits of cloud computing

Cloud computing has already gained ground across the business market, as an innovative and elastic provisioning model for Information and Telecommunications (IT) resources. Enjoying their second decade of existence, maturing cloud technologies continue to benefit and promote technology market and reform the expectations and capabilities of the IT industry. Cloud technology is based on a similar principle as web-based email clients, allowing users to access all of the cloud services without having to keep the bulk of that system on their own computers. Most people already use cloud computing services without realizing it. Google Drive, Dropbox and even Facebook and Instagram are all about cloud-based applications. Users send their personal data to a cloud hosted server that stores the information for latter access. Even though the cloud based applications are useful for personal use, they are even more beneficial for businesses that need to store and access large amount of data over a secure network connection compatible with security principles.

Cloud computing offers agility, especially for businesses that are trying to expand. For example, companies that require greater bandwidth to maintain superior functioning can easily achieve it by switching to the cloud. Moreover, cloud environment offers quick disaster recovery, maximum uptime and store almost unlimited volumes of data. It provides its users with the luxury of 24-hour functioning which increases its accessibility. Employees are no longer bound to office hours to access their file of interest and hence can work whenever they want.

Furthermore, the use of cloud computing appears to offer significant cost advantages. Cloud users that buy and manage cloud resources are constantly increasing and the requirements for provided cloud IT resources are continuously growing. This growth of demand force providers to get prepared to meet this level of demand by creating and maintaining the appropriate infrastructure. Established computer industry players have entered cloud market such as Amazon, IBM, Google, as have traditional telecommunications companies, such as AT&T. (Etro, 2009).

In addition, the operation costs are reduced, since users do not pay for equipment, maintenance and hardware upgrade. Businesses that migrate their IT system and data to cloud environment demand the required shared resources, instead of using proprietary infrastructures, reducing server and storage costs, software maintenance expenditures, network expenses (Hogan et al., 2013)

Cloud computing mainly adopts, a “pay-as-you-go” pricing model, giving the option to the users to pay for what they use. As a result, cloud computing adoption offers low start-up costs to businesses that aim to obtain a dominant ICT market share. Furthermore, the cloud creates an environment for rapid innovation and development for businesses that need to respond faster and cheaper to their potential demanding wills, based on different cost models than the traditional (Martens et al., 2012).

The cloud computing model promises new development opportunities and job creation, contributing to the economic growth of a business. The provision of cloud computing services has tremendous potential and cloud providers and small, upstart entrepreneurs have been some of the greatest beneficiaries from the cloud's empowering influence, since they have improved profitability and new revenue opportunities. In addition, the number of new Small Medium Enterprises (SMEs) is increasing, new job profiles are being derived from this necessity, more job positions are created, resulting to multiplier benefits and growth of the society’s economy (Etro, 2009).

3.3 Shift to the cloud

Businesses constantly gain more experience in the cloud and they shift their core business functions onto cloud platforms. Companies around the globe are greatly interested in cloud technology, by adopting cost advantageous solutions. But is cloud environment able to fulfill all the financial expectations? Towards this direction the Capital Expenditures (CAPEX), the Operational Expenditures (OPEX) and Total Cost of Ownership are introduced, highlighting the cost beneficial perspective of the cloud.

3.3.1 Capital vs Operational Expenditures

Businesses have two types of expenses, Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) and they both refer to money that is paid out of a company, but each one is managed differently for accounting and taxation purposes.

Capital expenditure (CAPEX) is the money a company spends to buy, maintain, or improve its fixed assets, such as buildings, vehicles, equipment, or land. A newly purchased asset is considered a capital expenditure, as well as when money is used towards extending the useful life of an existing asset, such as repairing the roof, building expansion, hardware purchases (wikipedia.org, 2019a). Thus, CAPEX refer to expenditures that benefit business in the future, such as the purchase of new equipment, but also include modifications to the existing assets. The type of industry a company is involved in largely determines the nature of its capital expenditures. In addition, capital expenditures reveal how many money businesses are investing in their future and also capture the potential growth of the business.

Operating expenditure is an ongoing cost for running a product, business, or system. (Wikipedia, 2019). For example rent, salaries, taxes, any expenses considered sales, general and administrative expenses on the income statement. Unlike CAPEX, OPEX do not benefit business in the future, since they are expenses that are required to keep the company in business on a daily basis. As operational expenses make up the bulk of business's regular costs, management usually tries to reduce the operating expenses, without affecting the quality or the production of the business. If the OPEX are too high the business can easily lose money, whereas high CAPEX can be offset by future benefits. Figure 8 sums up and illustrates the CAPEX and OPEX expenses.

Figure 8 CAPEX and OPEX expenses

Businesses have two options when it comes to deploy their own IT infrastructure. Their first option is to obtain new capabilities and equipment and consider it as a longer-term investment. An on-premise solution requires to pay up front capital costs (CAPEX) but it also allows for amortization over time. However, those assets are depreciated over time and the cost of maintaining the infrastructure, by securing and upgrading it cannot be neglected.

The other option is to obtain ICT infrastructure as an operating expenses. Many businesses are shifting from a model of software and hardware ownership to cloud environment, adopting a pay as you go model. For start-up businesses, OPEX can be an influential driver of cloud adoption, however larger and popular businesses migrate to the cloud, exploiting the financial benefits and flexibility and scalability of cloud environment.

Operating expenses are generally stable and used for the day-to-day costs of running a business, thus numerous businesses decide to shift IT investment from CAPEX and OPEX, by adopting cloud services. The cash –flows benefits are enormous, with small regular payments replacing upfront payments that can negatively impact business' finance.

The shifting from CAPEX to OPEX is very popular in hardware leasing (IaaS), which allows businesses to put the core infrastructure in the cloud and purchase infrastructure as a service, rather than obtaining on-premises computing. An aging on-premises infrastructure is expensive to upgrade and maintain and locks businesses into using equipment that will soon become outdated, whereas with cloud, the responsibility to handle upgrades fall on the service provider who have the systems and expertise on hand to eliminate downtime.

Apart from hardware leasing, software leasing is also rather popular. As already introduced, cloud computing offers PaaS and SaaS services. PaaS, provides both cloud Infrastructure and stack upon which applications can be built. This solution is ideal for businesses that want to build their own systems that completely fulfill their requirements but they also use the core infrastructure via IaaS services. Salesforce is a cloud-based software company that sells complementary suites of enterprise applications focuses on customer service, analytics and application development, marketing automation. In addition, SaaS services include applications that describe what users thing that cloud is. Popular providers such as Google Apps, Apple iCloud, Microsoft Hosted Exchange offer numerous applications that most of these are charged on a small monthly per user basis, eliminating up-front license costs.

3.3.2 Total Cost of Ownership.

Total Cost of Ownership (TCO) is a financial assessment intended to help buyers and owners determine the direct and indirect costs of a product or system (wikipedia). It is a purchasing tool which is aimed at understanding the true cost of buying a particular good or a service from a particular provider. It can be used in full cost accounting and provides the means for determining the total economic value of an investment including capital expenditures (CAPEX) and operational expenditures (OPEX) over an n-year period (wikipedia.org, 2019e). TCO is a critical metric when designing a new datacenter facility or selecting equipment.

The calculation of the TCO is a procedure that provides the means for determining the total economic value of an investment, including the initial capital expenses (CAPEX) and the operational expenses (OPEX). In the context of the cloud computing and especially from the provider's point of view, as represented by the datacenter, TCO corresponds to the estimation of the costs required to build and operate a cloud infrastructure.

According to the literature, there are several studies that have examined the TCO metric, pointing out the cost-benefit aspect of the cloud technology. In (!!! INVALID CITATION !!!) a method and a software tool for cost calculation and analysis was developed. The cost of building and operating a cloud, called as TCO, was divided into eight different categories that mainly represent fixed costs, such as setting-up and maintenance costs that providers need to bear during the whole lifecycle. In (Martens et al., 2012) a comprehensive TCO model was presented for the three service models of cloud computing (IaaS, PaaS and SaaS) describing cost types and factors. They analyzed the pricing schemes of different cloud models based on data from real cloud computing services.

An interesting approach was presented in (Filiopoulou et al., 2015), analyzing the TCO of the cloud computing business model. The components and the technical desing of the cloud were described using the main entities from the framework of the CloudSim(Calheiros et al., 2011), a toolkit for modeling and simulation of cloud computing environments. The different cost categories of TCO represented as classes were incorporated to extend the cloud business model, so that it becomes more complete. Taking into account the high cost of investments that providers need in order to build and operate a cloud, an approach and a corresponding metamodel were proposed, to model the entities that constitute a cloud environment focusing on the necessary techno-economical parameters. Furthermore, a SysML profile aiming to support the TCO of a cloud using the proposed metamodel was defined and implemented.

3.3.3 Present Value (PV)

In economics and finance, Present Value (PV), also known as Present Discounted Value, is the value of an expected income stream determined as of the date of valuation. The present value is always less than or equal to the future value because money has interest-earning potential, a characteristic referred to as the time value of money, except during times of negative interest rates, when the present value will be more than the future value (Moyer et al., 2012).

Present value calculations and, similarly, future value calculations, are used to value loans, mortgages, annuities, sinking funds, perpetuities, bonds, and more. These calculations are used to make comparisons between cash flows that don't occur at simultaneous times since time dates must be consistent in order to make comparisons between values. When deciding among projects as in which to invest, the choice can be made by comparing respective present values of such projects by means of discounting the expected income streams at the corresponding project interest rate, or rate of return. The project with the highest present value, i.e. that is most valuable today, should be chosen (Moyer et al., 2012).

3.4 Case study -Shift from CapeX to OpeX.

The shift from CAPEX to OPEX is more flexible, more tax-effective and includes the most up to date technology. Businesses benefit from significant cost advantages, especially start-up businesses benefit from these advantages, since they do not operate with internal IT infrastructure. But are that costs related with cloud computing really advantageous? Therefore, a case study has been developed, aiming to reveal the economic advantages that a business gains from cloud adoption, instead of maintaining its own infrastructure.

This case study is based on HuaNews, a hypothetical start-up company that engages into translation and displays of foreign news from all around the world. Since HuaNews is a start-up company there are no switching costs but the management has to decide whether it will support its own IT Infrastructure or adopt cloud solutions.

A software tool has been developed that calculates the Total Cost of Ownership (TCO) of any given ICT infrastructure. CAPEX and OPEX contribute to the calculation of the Total Cost of Ownership (TCO). It is based on a detailed methodology that includes all suitable parameters as inputs and estimates the TCO and the initial investment of an ICT infrastructure (Konstantinos et al., 2015).

Example of inputs are:

- Design of the system architecture requirements
- Parameterization of the system. (Infrastructure, storage, hardware, software, networking requirements, component life cycles, the costs of each of the combined

elements necessary in a solution including the cost of software licenses, upgrades, and expansions, power consumption)

- Economic inputs (Assets, Depreciation, Costing and Pricing details, component price evolution, cost of capital etc.).

Outputs that are related to the investment were calculated, taking into consideration the aforementioned inputs.

• Values of a number of economic indices, in both the short and the long-term, such as: Initial investment, CAPEX, OPEX, Cash flows, Payback period, Net present value (NPV), Total Cost of Ownership.

The specific case study, as presented in (Konstantinos et al., 2015), assumes that HuaNews will create 50 job opportunities including administrators and management staff, journalist, reporters. The business needs IT equipment that will provide the following services:

- Email
- Calendar
- Blog
- web hosting
- storage services
- backups
- VPN.

In the case study two options are examined and compared:

I. The purchase of proprietary IT infrastructure by (servers, storage, networking etc.)
II. Cloud adoption.

Through the development of the software the following assumptions were made:

- The appropriate software for the operation of the IT equipment is free (OSS)
- Maintenance and support costs are the same for both options.

The TCO for both options was calculated for three years, since three years are an adequate time period to valuate such a kind of investment

3.4.1 Option I: Proprietary equipment

Initially, it is assumed that HuaNews creates the IT department by purchasing and maintaining the equipment. The IT department includes 5 Servers Intel® Xeon® E5-2640 v2 (8 core, 2 GHz, 20MB, 95W), each one having the following characteristics: 2 processors with 8 cores per processor; 16GB of RAM memory; 4 NICs; 4 ports per controller; size U; 460W power supply and a total storage of 5TB SAS. The TCO of the business for the following three years is based on the CAPEX and OPEX expenses.

The CAPEX and OPEX of the business are analytically presented in Table 1 and Table 2.

Initial Cost of Infrastructure	**Quantity**	**Three Year Cost**
Servers	5	17.500 €
Total Storage (SAN)	5TB	35.000 €
Networking (Switch)	4	14.710 €
Faclities (PDU,KVM etc.) per rack	1	897,00 €
Cooling equipment per rack	1	717,00 €
Capital Expenditures		**68.824€**

Table 1 Capital Expenditures of the IT Infrastructure

OpEx (3 years)		**Price**	**Annual Cost**	**Three Year Cost**
Actual Operating Power (Richard, 2004)	308 Watts per server	0,22€/kwh	2.962 €	8.885 €
Actual Cooling Power	385 Watts per server	0,22€/kwh	3.702 €	11.106 €
Real Estate Rent	5 sq.m	5€/sq.m	300 €	900 €
Operating Expenditures			**6.964 €**	**20.891 €**

Table 2 Operational Expenditures (OPEX) of the IT Infrastructure

The initial investment (CAPEX) will reach a level of 68.824 € and the Operational Expenditures (OPEX) will be 20.891 € for 3 years. Thus, the estimated TCO for the required infrastructure will reach a total of 89.715 €.

3.4.2 Option II: Cloud adoption.

In the following section the TCO is estimated, based on operational costs of the cloud services. In this option the appropriate resources are derived from Amazon Web Service provider . The corresponding infrastructure requires virtual machines, each one costing of one large instance EC2 m2.xlarge and 1 TB SSD EBS (17.1 GB RAM, 1 TB HDD, 2 vCPU ~ 6.5 ECU).

As shown in Table 3 the total cost per month for the five VMs would be 455€, but by using the option of subscription for 3 years, the cost will be reduced to 323€ per month. Prices from other providers are of the same magnitude. For the above calculations it is assumed that each Amazon's VM is running on Linux, 24/7 for three years continuously; 50TB data transfer in ; 500GB data transfer out; 1 TB EBS storage; 10 million GET requests; 10 million PUT requests; Load Balancer 500GB for processed data. The total cost of using Amazon's cloud instances and services for 3 years, with the assumption that the price will not change, will be 58.093€ according to the current Amazon's pricing policy.

AWS VM (24/7)	Cost per month	Three Years
EC2 m2.xlarge + 1 TB SSD EBS	145€	5.398 €
Transfer	75 €	2.707 €
Load balancer:	22 €	780 €
Cloud Object Storage capacity	28 €	991 €
Cloud Object Storage requests	48 €	1.743 €
Total	**323€**	**11.619 €**

Table 3 AWS Virtual Machine Cost

3.4.3 Comparison of the two options

The comparison between the two options, points out the most advantageous solution. The present value (PV) is calculated (Brealey Richard) for each option, taking into consideration the monthly discount rate 10%. Therefore, PV for internal infrastructure is estimated 86.808€ and PV for amazon cloud solution is estimated 50.011€.

Table 4 depicts the annual comparison between the infrastructure cost and the cost of Amazon's cloud services.

Period	Initial Investment + OpEx	AWS Cost
Start	68.824 €	0 €
1st Year	6.964 €	19.364 €
2nd Year	6.964 €	19.364 €
3rd Year	6.964 €	19.364 €
Total	**89.715 €**	**58.093 €**

Table 4 Comparison of the Investment in the Internal Infrastructure and the Cost of AWS Cloud

Results show that this new company in the media industry can benefit by cloud adoption, instead of purchasing proprietary infrastructure. According with Table 4, there is a substantial cost difference between the two considered options, leading to the proposal of adopting cloud services to deploy in the business, instead of supporting proprietary infrastructure.

In addition, the cost flows are calculated and they refer to the manner or path on which costs move through a firm. According to Figure 9 the cost flow for the case of purchase proprietary equipment is higher than AWS cost, ensuring that cloud adoption is the optimal solution for HuaNews.

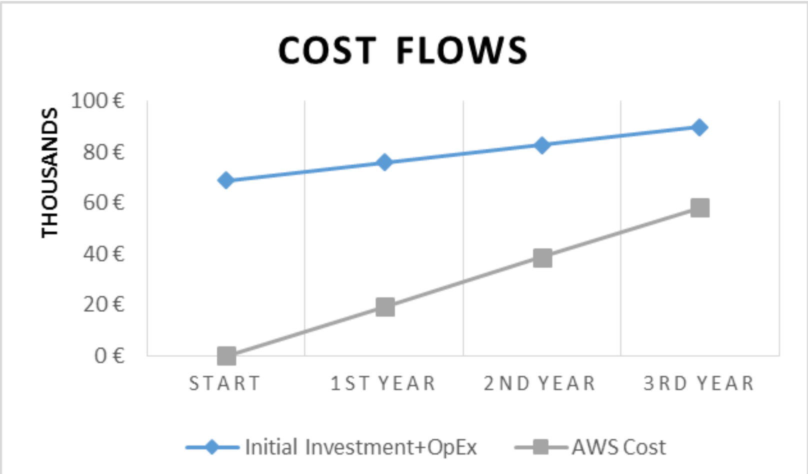

Figure 9 Cost flows - Comparison

According to the results of the case study, moving to cloud will save money. That includes the ability to have much more operational costs, flexibility, reliable security, all while controlling costs.

3.5 Diffusion of Cloud

Technology diffusion means technology adaption in the marketplace and the success of a technology innovation is a critical process(Liimatainen and Liu, 2014). It is usually assumed that modern technologies present immediately high rates of diffusion, however the process of diffusion is rather slow.

In the case of cloud computing diffusion describes the process by which cloud computing is adopted by a population and it points out that the adaption to the market demands that cloud services need to be technological and commercial attractive.

There are four cornerstones that cloud computing has to fulfill in order to reach adequate quality of service level (Liimatainen and Liu, 2014):

- *Efficiency* is the ability to avoid wasting materials, energy, efforts, money and time in doing something or in producing a desired result (wikipedia.org). Applying payment method "pay-as-you-go" of cloud computing, there are no wasted resources since users pay only for services procured, rather than provisioning for a certain amount of resources that may not or may not be used.
- *Scalability* is the property of the system to handle a growing amount of work by adding resources to the system (wikipedia.org, 2019d). This is one of the most valuable and predominant feature of cloud computing. For example a user can scale up data storage capacity or scale it down to meet the demands of the growing business. When business demand is increasing new servers can be easily added and when the demand is reduced business can return to the original configuration.
- *Robustness* is the ability of a computer system to cope with errors during execution and cope with erroneous input (wikipedia.org, 2019c)
- *Security* is the protection of computer system from theft or damage to their hardware, software or electronic data, as well as from disruption or misdirection of the services they provide (wikipedia.org, 2019b) Cloud security includes a set of policies, controls and technologies that contribute to the protection of cloud-based systems, data and infrastructure.

Cloud computing fulfills all the above diffusion parameters and has become one of the most discussed topics in the IT organizations. The current thesis focuses on IaaS services, the most straightforward model of the cloud and according to Gartner, the worldwide infrastructure as a service (IaaS) market grew 29.5 percent in 2017 to total $23.5 billion, up from $18.2 billion in 2016, and Amazon was the No. 1 vendor in the IaaS market in 2017, followed by Microsoft, Alibaba, Google and IBM (Morris, 2018).

The use of computing power and storage as cloud services in 29 European countries has been examined based on data derived from Eurostat , over the period 2014-2018.

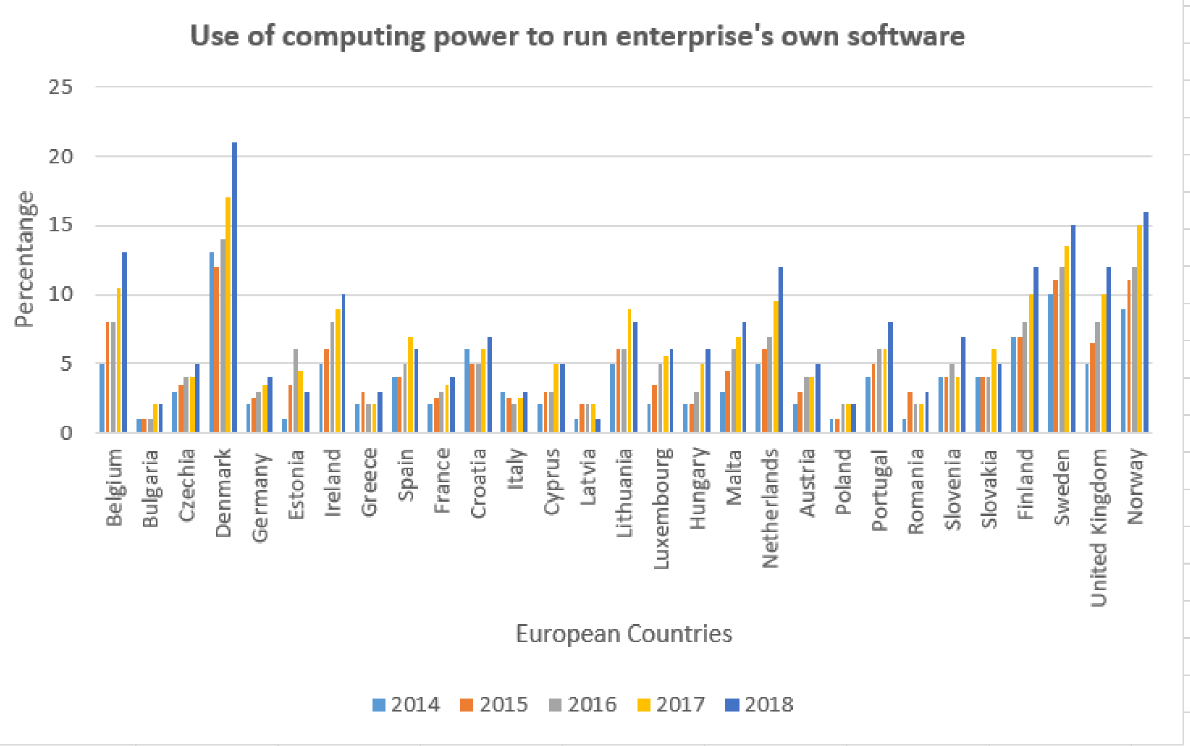

Figure 10 Use of computing power

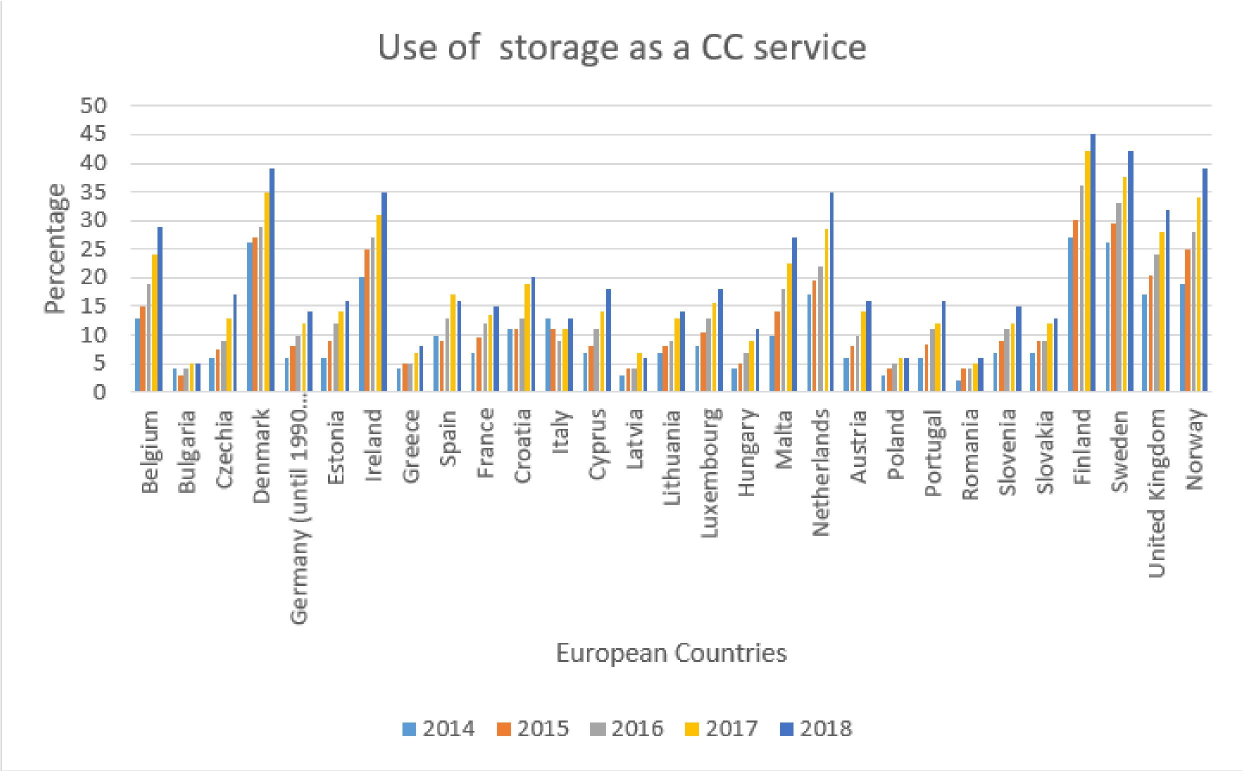

Figure 11 Use of storage as a cloud service

Figure 10 and Figure 11 reveal the exponential growth of the cloud industry and highlight that cloud technology is well adopted on the European market, since the rates of use of computing power and storage as cloud services have significantly grown over 2014-2018.

3.6 Cloud Pricing for IaaS services

Pricing is the process whereby a business sets the price at which it will sell its products and services and it may be part of the business's marketing plan. In setting prices, the business will take into account the price at which it could acquire the goods, the manufacturing cost, the market place, competition, market condition, brand, and quality of product (wikipedia, 2018b).

Following the above definition, cloud pricing is the process whereby a cloud provider sets the price at which it will sell its services. Cloud providers set the suitable price that increases their revenues and their market share. In addition, cloud users choose cloud services that offer high quality at a reasonable price. Therefore, the pricing of a service is an important process for both users and providers, therefore the current thesis focuses on both providers' and users' aspects, since these two sides strongly interact through the pricing process.

As mentioned in Chapter 2, cloud computing is composed by three models (IaaS, PaaS, SaaS) and the current thesis focuses mainly on the Infrastructure-as-a-Service (IaaS) model. Cloud providers offer numerous equivalent IaaS services at different price and the primary objective of a cloud provider is to maximize its revenues with the applied pricing technique. In addition, users aim to obtain the highest level of quality of service (QoS) for a reasonable price. Therefore, an optimal pricing scheme should satisfy both parties, since the cloud price holds a crucial and essential role as it strongly relates both providers and users and is considered to be one of the most essential metric that a cloud provider can adjust to promote the usage of its services (Al-Roomi et al., 2013).

Pricing strategies for IaaS services can be discerned in two categories:

- Fixed techniques: Providers set a price and keep it constant for an extended period of time.
- Dynamic techniques: The determination of price is dynamically changing based on factors, such as availability, time, cloud service features and according to the forces of the demand and supply of a real-time market(Andra, 2013, Al-Roomi et al., 2013).

3.6.1 Fixed pricing techniques

Fixed techniques offer assurance to end users because all the requirements, the costs and the deadlines are set down in advance. The budget of the business can be planned and there are no additional costs though the subscribed time period. However, if the need arises for changes to be done it is difficult to modify the agreement between user and cloud provider. It is an important limitation, especially for users, because it is difficult to add a new feature during the course of the project. In addition, these static approach of pricing has some limitations, due to the fact that providers reserve computational resources in advance and it is often hard to satisfy cloud users' requirements that suddenly arise. The most common fixed pricing schemes are presented below.

A) Usage-based model

One of the most common cloud pricing strategies of IaaS services is usage-based model that is based on "pay-as –you-go" model and it has become an important bridge between providers and users. This model charges the users for just the services they need, paying only for the required computing instances and just for the time they use them. It is similar to how someone pays for utilities like water and electricity and there are no additional costs or termination fees. In the case they need more resources, they simply request them from the provider(Grossman, 2009). For example, if a user needs additional 1500 computing instances for an hour, he pays just for these 1.500 computing instances and just for the hour that instances are used. Users know in advance the exact amount of money that will pay and cloud resources are reserved by providers for the requested and paid period of time (Al-Roomi et al., 2013). However, cloud provider cannot increase the price when the demand for the cloud instances is high or to decrease the price when the demand is low, therefore user may pay a higher price than the common market price. (Fox et al., 2009). This model is commonly implemented by Amazon, Windows Azure and Google..

B) Subscription-based pricing model

Subscription is another fixed pricing technique in which user subscribes with a specific cloud provider for a fixed price for a predefined long period of time. Subscribers typically commit to the services on a monthly or annual basis. Subscription-based pricing model is adopted by IaaS cloud providers and it is also known as reservation contract, since end user can reserve cloud resources for an agreed period of time. Many cloud-based workloads present a more predictable pattern, therefore for these stable applications cloud providers offer reserved instances. For example Amazon offers reserved instances and users make an annual or a three year commitment and they gain a billing discount up to 75%. (2018a).

C) Background of fixed pricing models

Fixed pricing schemes have been thoroughly examined in literature. Meinli (Meinl et al., 2010) analyzed two distinct reservation approaches and compared the approaches of IT service reservation via derivatives and yield management. The authors also analyzed the requirements of derivative market for cloud services. The proposed model highlighted the benefits for both providers and end users.

Yahyapour (Lu et al., 2011) introduced a model for resource planning based on IaaS services. The authors applied computational geometry to manage reservations of VMs through SLA negotiation and planning phase. They also analyzed the feasibility of each submitted reservation request and if the request could not be fulfilled an alternative aspect was proposed with backward or forward shifting in time.

In addition, Wang (Wang et al., 2011) examined resource reservation management challenges in cloud environment and the authors proposed an adaptive QoS-aware resource reservation approach that resource reservation requests were selectively fulfilled based on the possible QoS in the near future.

3.6.2 Dynamic pricing techniques

In dynamic pricing models the price changes dynamically based on factors such as demand and the required resources. The price is adjusted based on the time and costs involved or even due to fluctuating demand. Dynamic pricing methods help cloud providers to remain competitive in the cloud market and to maximize their revenues and profits since their prices comport with market conditions. Providers stay up to date on competitor pricing and general pricing trends. However this approach maybe discourage end users who prefer to know the price set in advance. In literature there are several research proposals based on dynamic pricing. The most common fixed pricing schemes are presented below.

A) Peak Pricing

In ”peak pricing” customers pay an additional fee during periods of high demand. Peak pricing is most frequently implemented by utility companies, who charge higher rates during times of the year when demand is the highest. The purpose of peak pricing is to regulate demand so that it stays within a manageable level of what can be supplied.

B) Time Based Pricing

Time-based dynamic pricing is popular in several different industries where demand changes throughout the day or where suppliers want to offer an incentive for customes to use a product at a certain time of day. Many industries change prices depending on the time of day, especially online retailers. Most retail customers usually shop the most during weekly office hours between 9AM-5PM, so many retailers will raise prices during the morning and afternoon, then lower prices during the evening

C) Background of dynamic pricing models

Rohitratana (Rohitratana and Altmann, 2012) introduced an agent-based simulation that patterned the interactions between users and providers in software market. Four dynamic pricing models were proposed. Users applied Analytic Hierarchy Process (AHP) and based on four decision criteria, such as finance, software capability, organization and provider, the most appropriate pricing scheme was selected. The results revealed that the demand-driven was the most effective method in ideal cases.

Mihailescu (Mihailescu and Teo, 2010) presented a dynamic pricing model appropriate for rational users. The authors proposed an auction-based pricing strategy for federated clouds, in which resources were shared among multiple cloud providers. The efficiency of the proposed model was compared with fixed pricing model, pointing out that dynamic pricing empowers users' welfare.

Li (Li et al., 2011b) introduced a real-time pricing algorithm for cloud computing resources. History utilization data were analyzed, aiming to indicate the price that had been mostly beneficial for the provider because it reduced its cost, allowing at the same time resources to be used more effectively.

Xu (Xu and Li, 2012) presented an infinite horizon revenue maximization framework to point out the dynamic pricing problem in an infrastructure cloud. In addition the proposed analysis was verified by numerical studies. The conclusions revealed interesting observations about the connection between the degree of demand dynamics and the optimal pricing policy.

Tordsson (Li et al., 2013) adopted a set of placement algorithms applying them to dynamic pricing scenarios, pointing out the cost-optimal cloud services. An experimental evaluation was conducted, using simulated deployments on cloud providers with pricing dynamic models. In addition the algorithms were compared, taking into consideration execution time, quality of solution and ration of successfully solved deployments cases.

The study of the fixed and the dynamic pricing models has pointed out that both categories, especially the dynamic pricing schemes, takes into considerations some of the most essential characteristics of IaaS cloud service. A well-motivated pricing policy is the principal key to the success of cloud services. Existing pricing models are often quite complicated. They are based on a multitude of factors, including resource allocation such as storage, CPU and memory, as well as on qualitative features offered by providers at an additional cost. Quantifying the bearing of both functional and non-functional attributes in determining the price is an important step towards obtaining a clear pricing strategy. Therefore this thesis proposes pricing models that estimate the extent to which each characteristic affects the total price of a service.

3.7 Pricing Factors

Pricing schemes are defined by factors that hold an important role to the shaping of the final price. In the context of this thesis the following pricing factors have been defined.

- **Resource Cost**: The amount of money the providers charge for cloud resources (storage, memory, compute power). Users with more demanding requirements are usually charged with higher price.
- **Lease Period:** The period that users will lease cloud resources from providers. In the context of this thesis an annual lease period has been chosen.
- **Functional attributes of users:** Features that define the functionality of the IaaS service.

Quality of Service (QoS): It includes qualitative attributes of cloud services that improve end users experience in cloud environment.

As mentioned above, the IaaS cloud services are described by functional and non-functional features. A functional attribute describes a technical detail or other specific functionality and defines what a system is supposed to accomplish (wikipedia, 2018a). The functional attributes of IaaS services are presented in Table 5.

Functional Requirements	
vCPU	A physical central processing unit that is assigned to a virtual machine (VM)
Memory	The amount of RAM that is assigned to a virtual machine (VM)
Storage	The amount of storage capacity of a virtual machine (VM).
OS	Operating System of a virtual machine

Table 5 Functional Attributes of IaaS services.

The non-functional attributes of cloud services describe the qualitative aspects of cloud provision rather than specific technological requirements (Armbrust et al., 2010). Cloud users mainly select services that fulfill their functional requirements and usually neglect the qualitative aspect of a service. At the same time, they struggle to obtain the best possible performance at a minimum cost. In the context of this thesis, both functional and non-functional attributes have been examined, indicating their impact on price. According to the relative literature there has been a significant gap, about the influence of non-functional attributes and their crucial role in pricing policy.

The non-functional and the functional attributes were chosen from Cloudorado (https://www.cloudorado.com), a cloud computing price comparison service.

The non-functional attributes, as derived from Cloudorado, are presented as follows:

- **Encrypted Storage**: The storage volume is encrypted.
- **General Data Protection Regulation (GDPR)**: The provider is compliant with current EU law on data protection (2018b).
- **Backup Storage:** If storage –based backup is available or not.
- **Free Support:** Support cost is included in the price of the basic plan of the provider.
- **Burstable CPU:** The CPU allocation can be either fixed or can burst to a higher capacity if current conditions allow it. Burstable CPU allows gaining extra CPU power at no additional cost.
- **Resource Usage Monitoring**: Users can monitor resource utilization (i.e CPU, RAM, disk, network) in their cloud servers. This feature is vital for performance and capacity management.
- **Application Programming Interface (API):** A management API is available for automating cloud servers life-cycle or not.
- **One Account for All Locations:** There is one account and single interface to manage all different locations or separate accounts for each location**.**
- **Image from Cloud Server:** This feature creates an image from an existing VM and this image is deployed to other cloud servers.
- **Limited Free Trial:** Cloud companies offer a free trial of their services for a limited period of time or for a certain amount of credit to be spent on cloud services, so that customers can use them to run tests.
- **Auto-scaling:** This feature adjusts computational resources aiming to maintain the predictable performance.
- **Service Level Agreement (SLA) Level:** Describes the uptime SLA level expressed in percentage points of availability. The corresponding value varies from 99,90% until 100%**Supported Operating System** MS Windows/ Linux

The non-functional attributes are classified into four (4) categories that describe the quality of services. Furthermore, a fifth category has been defined which includes functional attributes, known as Performance. The four (4) non-functional categories and the functional category are presented below.

- **Security**: It refers to security policies, technologies and controls deployed to data (Beran and Violato, 2010).

- **Availability**: It is defined as the percentage of time and informs if a cloud service is available (Gangwar et al., 2015). It embodies the idea that cloud users from anywhere and anytime can access services and data.
- **Elasticity**: It refers to the ability of cloud technology to manage, predict and adapt responsiveness of a service, based on real time demand (Raut et al., 2018).
- **Usability**: It describes the user-friendliness of the IaaS platform (Glinz, 2007).
- **Performance**: It refers to various functional requirements of IaaS related to performance.

Figure 12 illustrates the pricing factors.

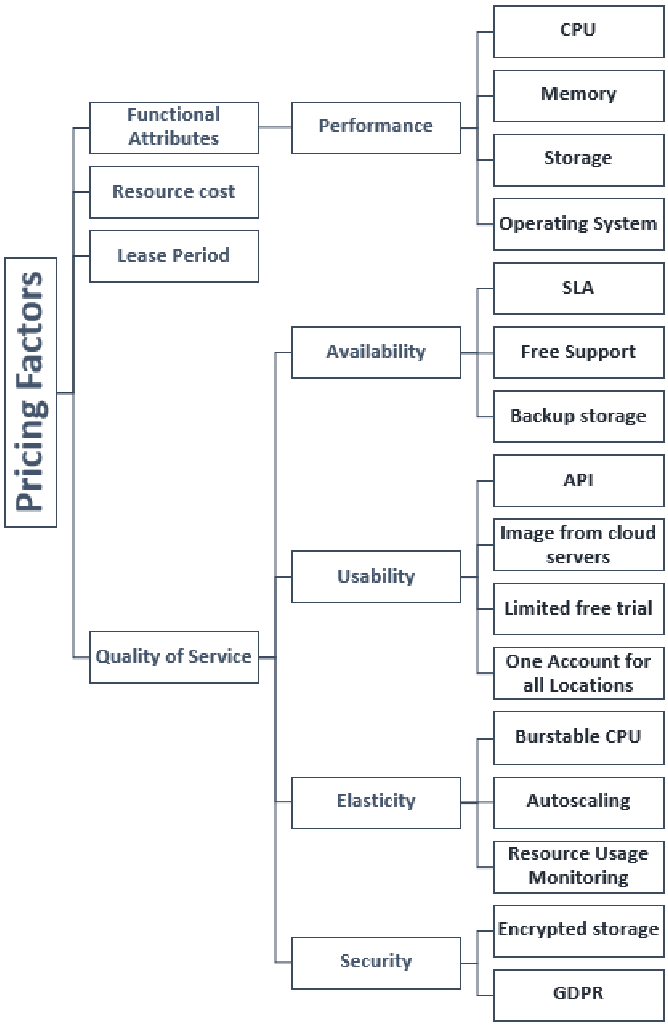

Figure 12 Pricing Factors

The above pricing factors were used for the implementation of the proposed pricing schemes. The selected pricing factors precisely describe and define the IaaS services, highlighting both functional and qualitative aspect. Numerous IaaS bundles, based on the pricing factors, have been collected from Cloudorado , in order to implement the proposed schemes and thoroughly examine the results of each technique.

Cloudorado is a price comparison service of cloud computing providers, focusing on Infrastructure as a Service (IaaS) providers. It could also be described as a price calculator for multiple cloud hosting providers, since the comparison is performed by calculating price for individually set server requirements. Cloudorado does not point out the cheapest cloud computing provider, since each provider has different pricing schemes, different packages and different relations among resources. It rather finds the cheapest provider for end users' needs. It accepts specifications on each customer's needs such as memory, storage, processor computing capabilities and operating systems and returns a comparison of different cloud services based on price. The platform also allows applying filters based on non-functional requirements such as security, reliability and cloud management features.

The development of the proposed pricing schemes has focused on the aforementioned pricing factors and the implementation of the schemes was based on numerous collected cloud bundles, derived from Cloudorado . At the beginning of this thesis the IaaS instances are exclusively described by functional attributes, therefore the collected cloud bundles from Cloudorado are described by functional criteria. However, since the quality of the cloud environment cannot be neglected, therefore cloud bundles were upgraded by adding qualitative features driven by relative literature (Glinz, 2007). Through the implementation of each pricing model, different pricing factors were chosen, based on the characteristics of each method and therefore data for the implementation of each method have been collected. The criteria for the data collection were based on Amazon's cloud instances, since Amazon is the leading cloud industry and the pattern of the cloud instances can be considered reliable for the data collection. In addition, the dataset has been constantly updated, because prices are constantly changing.

The total number of the selected bundles has derived from twenty-six (26) cloud providers, shown in Table 6. However, through the implementation of each pricing model the criteria for the data collection change, therefore the number of cloud providers that fulfill the specific criteria varies. For example, the dataset for the development of Hedonic price index was derived by twenty-six (26) providers, whereas the data collection for the implementation of DEA-oriented pricing model has been derived by twenty-three (23) providers.

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

Table 6 Cloud providers

3.8 Proposed pricing methods

The current thesis has developed pricing methods for IaaS services, focusing on both providers' and users' perspective. Providers' viewpoint examines and points out the pricing factors that contribute to the shaping of the final price, whereas users' aspect highlights the pricing factors that users consider more essential for the determination of the cloud price.

Economic-inspired methods have been used to approach cloud pricing problems, such as:

- Hedonic Price Index

Data Envelopment Analysis (DEA)

Furthermore, decision making method and statistical causal method have been applied to address economic issues of cloud pricing such as:

- PairWise Comparison (PWC) frameworkStructural Equation Model (SEM)

Hedonic method, DEA and SEM have been used in order to highlight providers' aspect, whereas PWC captures users' perspective. The implementation of the above techniques has been based on cloud bundles derived from Cloudorado according to specific criteria.

Furthermore, pricing of cloud brokerage services was examined, by overviewing financial methods that examine the profitability of cloud broker.

Chapter 4 Pricing IaaS services based on Hedonic Price Index

4.1 Outline

The cloud pricing procedure is a multidimensional function and represents the supported cloud characteristics. Providers develop and adopt different pricing models, optimizing their business strategy and maximizing their profits. In the context of this chapter the hedonic model is introduced in order to develop a pricing model and point out at what extent the functional and the non-functional attributes contribute to the shaping of the final cloud price.

4.2 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 (Rosen, 1974) . The main assumption that 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 literature, 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. (Triplett, 2004a). Rosen first presented a theory of hedonic pricing in his paper (Rosen, 1974). He argued that an item's total price can be thought of as a sum of the price of each of its homogeneous attributes. An item's price can also be regressed on these unique

Chanel (Chanel et al., 1996) suggested a price index of art market based on regression, using the full set of sales. The price index has been constructed for Impressionists and their followers and the various estimators have been compared by applying bootstrapping techniques. The following equation describes the hedonic method that has been applied:

$$p_{it} = \sum_{k=1}^{m} \alpha_k v_{ik} + \sum_{\tau=0}^{t} \sum_{j=1}^{n} \theta_{j\tau} w_{ij\tau} + \sum_{\tau=0}^{T} \delta_t c_{it} + \varepsilon_{it} \,. \qquad (1)$$

Where p_{it} denotes the price in year t, a_k and θ_{it} can be interpreted as prices of the various characteristics that describes the commodity, δ_t is the average price of a characteristic-free commodity in year, υ_{ik} represents time-invariant characteristics (e.g the dimensions of a painting),ω_{ijt} define time-varying characteristics (e.g the changing owners of a painting), c_{it} is an independent value which is equal to one if a transaction on commodity i occurs in year t and zero otherwise t and ε_{it} is a random disturbance

Baltas (Baltas and Freeman, 2001) introduced a hedonic price model which examined the structure of a rapidly evolving industrial market. The proposed model addressed the problem of intersegment and interfirm heterogeneity and highlighted how differences among segments and among vendors could lead to price discrimination strategies. The following equation described the hedonic function between price of the product and its attributes. The price was considered to be a dependent variable and the attributes of the product as independent variables the regression model.

$$\ln P_{ti} = a_m + \sum_j \beta_j x_{ij} + d_t + \gamma_k + u_{it} \qquad (2)$$

Pi was the price of the product i, β_j described the regression coefficients that determine the magnitude of implicit prices, x_{ij} was the j characteristics of the i model, υ_{it} was the error term, d_t was the intercept of the year t, γ_k were segment-specific intercepts.

Moulton (Moulton, 2001) pointed out that the adoption of hedonic methods for calculating price statistics had exponentially increased and he also studied the role of hedonic methods in U.S statistical agencies. The current paper also highlighted the factors that had contributed to hedonic methods adoption but also examined potential misinterpretations about the implementation of the hedonic methods in the agency environment.

Kihal (El Kihal et al., 2012) examined how to increase the transparency among vendors by developing two price methods. The first method was based on hedonic methods and the second method describes a model, called Prico (Pricing Plan Comparison) that also included offers from competitive providers. The pricing policies of five (5) IaaS providers were used for the implication of the model. Cloud instances from Amazon, Google, IBM Cloud, TerreMark and Microsoft Windows Azure were chosen for the implementation of the models. The conclusions of the study helped users to choose the least expensive provider for their needs. The following equation describes a linear regression model

$$BA_p(X) = \beta_{0p} + \sum_{i \in I} \beta_{ip} \cdot x_i + \varepsilon_p \qquad (3)$$

BA_p describes the billing amount for using the service X, ε_p error term represents the residuals of the assumed functional form of the characteristics, β_{ip} , are the hedonic prices of the characteristics i that increase the transparency by decomposing the billing amount of each provider into monetary values of IaaS characteristics.

Hedonic indices can be used to develop a quality-oriented price index of a service. These indices accomplish end users to maximize utility and producers maximize profits. In the context of the hedonic indices it is possible to adjust the price of a service for its quality not quantity, by estimating 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.

Hedonic methods are fast to apply and simple calculations are needed. It is of high interest that these methods can estimate values based on actual choices Hedonic price indices can be easily modified even if no new products exist, or if all prices remain the same. 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:

$$P_i = f\left(X_i\right) \quad (4)$$

where P_i is the price of a variety (or a model) i of the considered product and Xi 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:

$$\begin{aligned} &P_i = b_0 + b_1 \cdot X_{1i} + b_2 \cdot X_{2i} + e_i, \\ &i = 1, \ . \ . \ . \ , \ N \end{aligned} \quad (5)$$

where bi 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

$$
\begin{aligned}
&P_{im} = b_0 + b_1 \cdot X_{1i} + b_2 \cdot X_{2i} + e_{im}, \\
&i = 1, \ ..., \ N \\
&P_{im+1} = b_0 + b_1 \cdot X_{1i} + b_2 \cdot X_{2i} + e_{im+1}, \\
&i = 1, \ ..., \ N
\end{aligned}
\qquad (6)
$$

In the context of this thesis, the vector of characteristics Xi, corresponds to the configuration of the IaaS cloud services assumed to affect the price, including functional and non-functional characteristics such as RAM size, number of CPUs, memory size, bandwidth, encrypted storage, Autoscaling, SLA. etc. As also assumed in the relevant literature regarding hedonic regression the independent variables are chosen among the ones that include performance-related product and service attributes, which represent not only value to the consumer but also resource cost to the producer.

Moreover, the functional form adopted for the evaluation of the hedonic regression is the linear, since it is usually preferred in the hedonic theory, mainly due to the fact that linear functions are easy to estimate and interpret and despite the fact that for products such as high-tech goods, the loglinear model may be used, among as it most likely reduces the problem of as prices tend to be log-normally distributed.

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.

The current thesis has initially examined the price index construction based exclusively on functional characteristics (Mitropoulou et al., 2015, Mitropoulou et al., 2016). Taking into consideration, the key role of the quality in the shaping of the price, the price index has been extended and a different approach in the construction of the price index has been introduced, including qualitative attributes such as encrypted storage, autoscaling and service level agreement (SLA) (Mitropoulou et al., 2017). The functional and non-functional characteristics are presented in detail in an earlier section.

4.2.1 Price Index Construction based on functional attributes

The price index was constructed for IaaS cloud instances, the most straightforward cloud service. As mentioned above, data collection were derived from Cloudorado and the number of the collected bundles is 2742. Cloud providers were categorized into groups, based on their location. The most popular geographical continent for cloud providers is North America with 21 out of 26 to have datacenters located there. In addition, 16 providers are located in Europe, Australia and Asia follow with 8 providers each one, South America with 4 providers and finally Africa comes last with 1 provider. Table 7 presents cloud providers and the location of their datacenter

Providers	**Location**
Amazon	N. America, Europe, Asia, Australia, S. America
Atlantic.net	N. America, Europe
Bitrefinery	N. America,
CloudSigma	N. America, Europe
Dimensiondata	N. America, Europe, Asia, Australia, S. America, Africa
eApps	N. America,
ecloud24	Europe
Elastichosts	N. America, Europe, Asia, Australia
Exoscale	Europe
GIGENET	N. America,
GOGRID	N. America, Europe
Google	N. America, Europe, Asia
HYVE	N. America, Europe, Asia
JoyentCloud	N. America, Europe
Lunacloud	Europe
M5	N. America,
Ninefold	N. America, Australia
Openhosting	N. America,
Rackspace	N. America, Europe, Australia
Servermule	Australia
Storm	N. America,
StratoGen	N. America, Europe, Asia
Terremark	N. America,

Vpsnet	N. America, Europe, Asia, Australia, S. America
Windows Azure	N. America, Europe, Asia, Australia, S. America
Zettagrid	Australia

Table 7 Cloud providers the location of their datacenters

Four linear price indices were constructed. The first price index was based on the whole dataset and the other three were implemented over the bundles of the Europe, North America and the rest of the world.

The collected IaaS bundles and their corresponding values, are described by the following functional attributes, as presented in Table 8.

Cloud Attributes	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)

Table 8 IaaS attributes

The construction of the hedonic price index was mainly based on the above IaaS characteristics but a few more attributes have been selected, in order to participate in the proposed pricing model. These 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 contribution of the *Transfer In* to the shaping of the price was not substantial to consider, because many providers such as Amazon and ecloud24 charge customers only for the outgoing traffic, thus with no loss of generality the corresponding value of the *Transfer In* was considered to be at 1GB per month. In addition, *Time on* was set at level of 100% availability per day and the default offered values of non-distributed resource has been selected.

Cloud providers adopt different pricing policies and many providers such as, Amazon, Rackspace and GoGrid use price bundling, therefore the closest to each customers' requirements package of resources, was considered acceptable. All of the attributes of the IaaS instances are numerical apart from the operating system and the subscription that participate as dummy variables. The values for operating system is 0 for Windows and 1 for Linux, and the corresponding values for subscription is 1 in the case that subscription is compulsory and 0 if the subscription is not needed.

A linear price index based on the whole dataset was constructed and the hedonic model's parameters were estimated by the use of ordinary least squares (OLS). The derived equation is presented below:

Price ($) = 83,8+ 27,7 * CPU + 0,223 * Storage + 18,7 * RAM +25,8 * OS + 0.08 * Transfer Out – 75,3* Subscription (7)

The results of the hedonic pricing method, based on the whole dataset are summarized in Table 9

Coefficients	Value
Constant	130,499***
CPU	14,532**
Storage	0,249***
RAM	20,434***
OS	-16.91
Transfer_OUT	0,076***
Subscription	-85.82

Coefficients	Value
Constant	130,499***
CPU	14,532**
Storage	0,249***
RAM	20,434***
OS	-16.91

Transfer_OUT	0,076***
Subscription	-85.82

The estimated R^2 value is 57,5% and points out the description of the price index by the linear model, may not be the most appropriate choice. However, the output of the hedonic price index points out that all attributes are significant to the shaping of the cloud price. In particular, *Subscription* is the attribute with the greater impact on the shaping of the price and also the high value of the constant that describes a fixed monthly fee, justifies the leading role of subscription in the shaping of the price. Furthermore the *CPU*, the *RAM* size and the operating system appear to have a significant effect on price, whereas, storage has a minor impact on price.

In addition to the above index, three regional price indices were also constructed for Europe, North American and the rest of the world. The corresponding results are presented in Table 9.

Coefficients / R^2	**Europe / 52,9%**	**North America / 55%**	**Rest /86.3%**
Constant	27.5	145	254
CPU	21,97	15.3	14.3
Storage	0.0595	0.311	0.159
RAM	13,5	16.6	20.2
OS	27,3	19.1	25.5
Transfer_OUT	0.0504	0.08	0.157
Subscription	-0.3	-25.4	-0.9

Table 9 Regional Price Indices

The main differences among the results of the linear hedonic model across regions and the whole dataset are graphically illustrated in Figure 13. Examining the results of the four linear price models it is interesting to focus on the value of the constant and the differentiations it reveals across the datasets. The results of European price index, which was based on a dataset of 402 bundles, point out that the constant has the lowest value equal to 27.5, revealing that the monthly fees that European providers impose do not influence the price of IaaS instances. In addition, the low value of R^2, indicates that Europe still lacks from a coherent way of pricing and each provider follows its own pricing scheme.

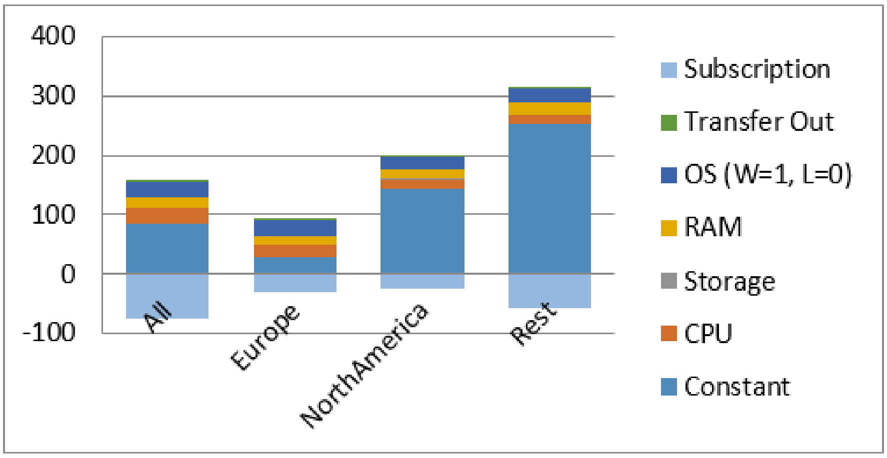

Figure 13 Contribution of the coefficients to the shaping of price by continent

The linear hedonic model related with 544 bundles of providers located in North America and the price index in the rest world related with 288 cloud bundles of 20 different providers highlight the crucial role of constant. The value of constant in the first case equals with 145, whereas in the second case equals with 254. This is in accordance with the higher value of R^2 in North America, where at the same time the constant has an also higher value, as well as in the rest of the world dataset, where R^2 has an observably higher value, together with an observably higher constant. The high values of the constant point out that the cloud market is not mature to adopt a competitive pricing model, therefore the monthly subscription is essential.

Comparing the results of the price indices for all the continents, shows that *CPU*, *RAM* and operating system (OS) highly contribute to the price, whereas storage has a lower impact on price. In addition, traffic is more valued in the Rest set and the *Transfer_OUT* attribute is morevalued in the Rest set than the other datasets.

4.3. Price index and non-functional attributes

As mentioned above, the current thesis examines the essential role of the quality in the shaping of the final price of cloud services. Therefore, the hedonic model of the previous section was extended, in order to include non-functional attributes as well (Glinz, 2007). Furthermore, a new price index, which exclusively includes functional attributes, was constructed, in order to present a constructive comparison between the two indices.

The first price index is based on the 4 functional attributes, i.e. *cpu, memory, storage,* OS and then a second price index is constructed, by adding 13 non-functional attributes. The dataset of the previous hedonic model was updated, since the criteria for the data collection were modified. In addition, the *Transfer_OUT* attribute was excluded, since it had a minor impact on the shaping of the final price.

The dataset used for the development of the hedonic model was also derived from Cloudorado . The Cloudorado platform, apart from functional attributes supports non-functional requirements as well, such as security, reliability and cloud management features. Data collection focused on 4 functional and 13 non-functional properties. The values of all attributes are shown in Table 10.

Requirements Category	**Attributes**	**Values**
Functional Attributes	CPU (v cores)	1x, 2x, 4x, 8x, 16x, 32x
	RAM (GB)	2, 4, 8, 16, 32, 64, 128, 256
	Storage (GB)	50, 100, 200, 500, 1000, 2000, 5000, 10000
	OS	Linux/ Windows
Non- Functional Attributes	Encrypted Storage	Yes/ No
	Safe Harbor / EU Directive 95/46/EC	Yes/ No
	SLA	99.90%/ 99.95%/ 99.98%/ 99.99%/ 100%
	Backup Storage	Yes/ No
	Free Support	Yes/ No
	Burstable CPU	Burstable / Fixed

	Auto-scaling	None/ Vertical/ Horizontal/ Both
	Resource usage Monitoring	Yes/ No
	Web Interface	Yes/ No
	API	Yes/ No
	One Account for All Locations	Yes/ No
	Image from Cloud Server	Yes/ No
	Limited Free Trial	Yes/ No

Table 10 The values of functional and non-functional attributes of IaaS bundles.

The functional attributes are treated as numerical variables and the non-functional attributes are treated as dummy variables. Even though the operating system attribute is considered to be a functional attribute is also treated as dummy variable with two different options, 0 for Linux and 1 Windows.

The dataset collection was based on specific criteria, combining functional and non-functional attributes, as shown in Table 10. The number of the collected cloud bundles is 806 and they were derived from 23 provides, as shown in Table 11 In the previous section, the construction of the price index was based on cloud bundles, derived from 26 providers. The bundles collection was modified and the supported providers were changed, since the cloud attributes and the corresponding values were altered.

Cloud Providers	
Microsoft Azure	Stratogen
Amazon	eApps
Google	Data Dimension
CloudSigma	CloudWare
Atlantic.net	ZippyCloud
M5	Exoscale
Elastichosts	Vps.net
Bitrefinery1	Dreamhost

Storm	Zettagrid
RackSpace	CloudSolutions
e24cloud.com	Gigenet
Joynet	

Table 11 Cloud IaaS providers

4.3.1 Price index construction based on functional attributes

The construction of the current hedonic model that exclusively includes functional cloud attributes is based on features such as *CPU, RAM, storage* and *operating system*. Table 12 presents the functional attributes and their corresponding values, used through the data collection procedure from Cloudorado.

Requirements Category	**Attributes**	**Values**
Functional Attributes	CPU (v cores)	1x, 2x, 4x, 8x, 16x, 32x
	RAM (GB)	2, 4, 8, 16, 32, 64, 128, 256
	Storage (GB)	50, 100, 200, 500, 1000, 2000, 5000, 10000
	OS	Linux/ Windows

Table 12 Values of functional attributes of IaaS services

The following equation represents the equation of the hedonic model and also in Table 13the corresponding results of the hedonic pricing method are summarized.

Price ($) = 242,04 +21,27 *CPU +16,32*RAM+ 0.09*STORAGE+ 15,12*OS (8)

Coefficients	**Values**
Constant	242,04***
CPU	21,37***

RAM	16,32***
Storage	0,09*
OS	15,12***

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

Table 13 The contributory value of each functional attribute

The value of R^2 for the regression model equals with 37,1%, pointing out that the model does not succeed in describing the variance of the model and construct an effective price index. Based on the results of the model, the constant, which represents a fixed annually fee, has a major impact on the shaping of the price, followed by *CPU* and the *RAM* size. In addition, the operation system attribute has a significant contribution to the price index, whereas storage presents minimal influence in price.

4.3.2 Price index construction based on functional and non-functional attributes

The price index of the previous section has been upgraded by including functional and non-functional properties and also the subscription characteristic is considered to have a fixed value, representing 'Annual Subscription' like the previous hedonic model. The estimated parameters of the price index construction are presented in descending order, as shown in Table 14.

Coefficients	**Values**
Constant	165,5***
Safe Harbor / EU Directive 95/46/EC	50,62***
Image from cloud server	28,28**
Burstable CPU	27,09***
One Account For All Locations	25,68***
Encrypted storage	17,30***
OS	14,24***
RAM	13,45***
CPU	11,98*
Support included	8,71*
Auto-scaling	4,07***
API	2,95*
SLA Level	1,33**
Back-up storage	1,29*
Resource usage monitoring	0,84*

Storage	0,12***
Limited free trial	0,06*

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

Table 14 The contributory value of each non -functional and functional attribute

The R^2 value was calculated at a level of 73.8%, meaning that a much higher percentage of variance is described by this model. Based on the relative literature if a regression model estimates a high value of R2 then the closer the data points will fall to the fitted regression line (Triplett, 2004b). According to the particular hedonic model, a high value of R^2 indicates that all parameters are significant and they contribute to the shaping of the price.

Based on the results, the *constant*, that represent the annual subscription, seems to hold a determinant role in the shaping of the cloud price. Providers define the subscription and the users pay in advance for the services they are going to use for a pre-defined period of time. The high value of subscription it is rather expected since subscription is the backbone of IaaS companies' revenue streams and it is an important and profitable process.

In addition, features that are directly related with cloud security, such as the *EU Directive 95/46/EC* attribute, which refers to the protection of personal data and *encrypted storage*, seem to be crucial. Their corresponding values justify why security is one of the most important user concerns of cloud environment.

Furthermore, features that describe the well-established operations of cloud, such as *limited free trial, API* and *resource usage monitoring* have a minor impact on the cloud price, whereas features that manage an increased workload, such as the *burstable cpu* attribute, contribute significantly in the shaping of the price In addition, *Storage* has a minor impact on price, which also supports the finding of the previous price index which was exclusively based on functional attributes.

4.4 Comparative analysis.

Since, quality is a challenging issue of the cloud environment, its key role in the determination of the price was examined. Therefore, an upgraded price index was developed, based on the functional and the non-functional cloud attributes, examining the contribution of cloud attributes in the shaping of the cloud price. In addition, a price index that exclusively includes functional attributes was constructed as well. The results of the two indices are compared in the following paragraphs, in order to verify the crucial role of quality in the determination of the cloud price.

According to the results of both price indices the constant parameter that represents the annual subscription, has the greater impact on the shaping of the price. In a subscription-based pricing model, users pay upfront, prior to receiving access to preselected cloud services. Subscription length influences the final price and a longer period of time subscription is often translated to lower cost. Users are aware of the cost they will pay, however they can overpay or underpay for services. A pricing policy based on subscription benefits providers, because they ensure a predictable revenue stream from users for a specific period of time. It also boosts providers to improve their services, so users are willing to renew their subscription. However, a low value of the subscription will difficult provider to cover their costs, whereas an expensive subscription will prevent end users to adopt cloud services.

An overall graphical presentation of the coefficients of the functional non-functional attributes is illustrated in Figure 14. Blues bars represent non-functional coefficients of the price index, while red bars depict functional coefficients. Figure 14 reveals that cloud providers consider that non-functional attributes prevail over functional attributes, through the pricing process.

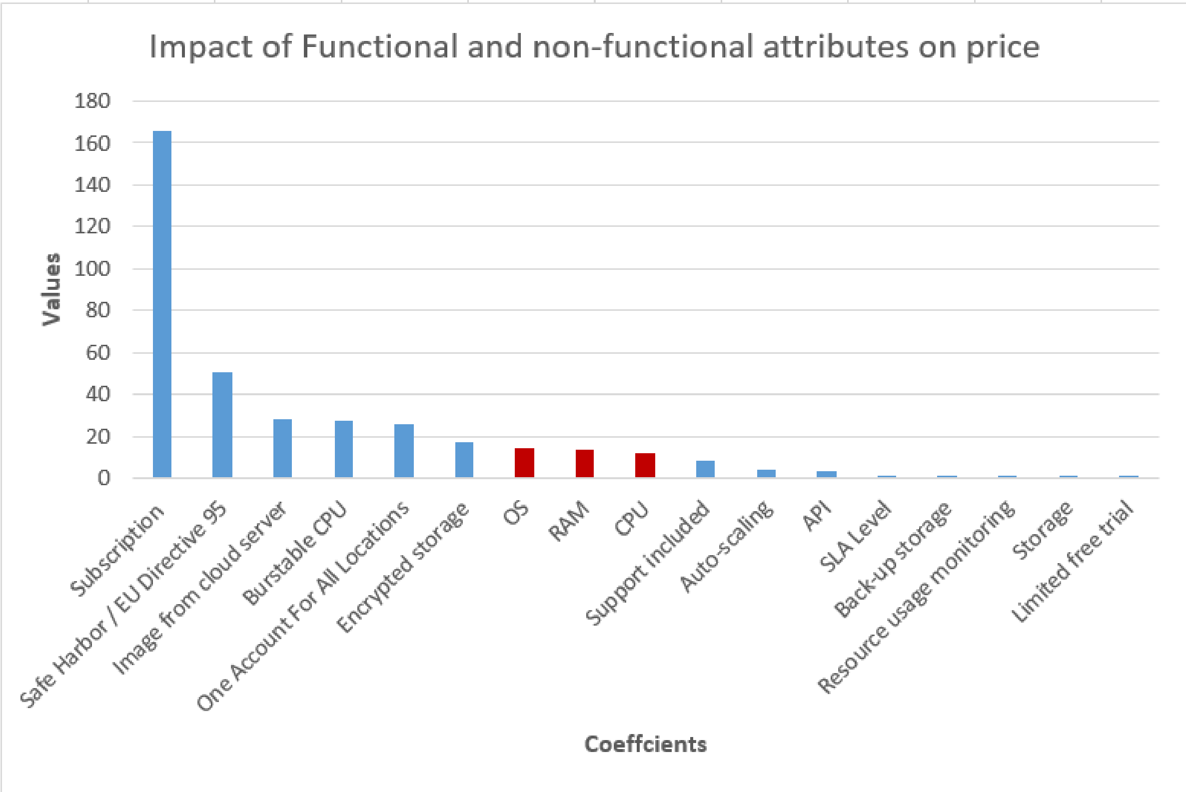

Figure 14 Functional and Non-functional coefficients of price index

The high values of non-functional attributes reveal that they affect the price more than functional attributes. *Safe Harbor / EU Directive 95/46/EC* and encrypted storage features have a great impact on the price, highlighting the essential role of security in the pricing of a service. The estimated coefficient of *the One account for all locations* feature reveals that the ease of access and use a cloud service are also of great importance through the pricing process. TheBurstable CPU attribute is also highly significant, whereas storage and limited free trial parameters seem to affect less the final pricing of cloud bundles of services. In addition the *CPU*, the *RAM* size and the *operating system* appear to have also significant effect on price, according to both price indices, whereas, *storage* has a minor impact on price.

The output of the upgraded price index confirms that the contribution of non-functional attributes in the shaping of the price is highly essential. Non-functional attributes are not abstract concepts that are considered only through the design of the cloud service but then neglected through the implementation process. They are engineered into cloud services just like functional attributes and they strongly contribute to the determination of the final cloud price.

Chapter 5 Pricing IaaS based on Structural Equation Model (SEM)

5.1 Outline

In Chapter 4 hedonic methods have been applied on IaaS services and have examined the impact of the qualitative and quantitative cloud attributes on price. Even though the aforementioned price indices certify the essential role of the non-functional attributes in the shaping of the price, it is not clear at what extent the requirements that define and judge the operation and the function of the cloud influence the determination of the cloud services price.

Based on the relative literature about functional and non-functional requirements, the need for the categorization of the cloud attributes has occurred and cloud attributes were grouped into 4 non-functional categories, security, availability, usability, elasticity and one functional, performance. The categorization of the cloud attributes was introduced in the previous section.

The Structural Equation Model (SEM) is employed in order to develop a new pricing model, able to capture the providers' viewpoint and examine the impact of each category over price. This model differs from previous pricing schemes, as it presents more accurate conclusions about the relations among price and functional and non-functional categories.

5.2 SEM Background

Structural Equation Model (SEM) is a multivariate statistical analysis technique that is used to analyze structural relationships and can be described by a combination of factor analysis and multiple regression analysis. SEM is more powerful than regression analysis and has been applied into various research fields

SEM is a collection of statistical techniques, aiming to quantify the relations among variables, offering a flexible implementation of a theory causal model (Ullman and Bentler, 2012, Chin, 1998). The main advantage of this model is that it outweighs a common regression analysis, modeling relations among multiple variables, assessing all pathways of a relationship. A SEM-based model includes the observed variables which are directly measured and the latent variables that cannot be directly measured. The observed variables that define a latent variable are addressed as indicators and their causal relation with the latent variable determines the measurement model (Jöreskog, 2004)

SEM distinguishes two measurement models, the reflective and the formative (Diamantopoulos et al., 2008) and Figure 15 illustrates the different causal structures. In a reflective approach the indicators should not affect the latent variable and a latent variable is posited as the common cause of item or indicator behavior. The causal action flows from the latent variables (e.g security, availability) to the indicators. Modification of the latent variable causes changes in indicator behavior. However, modifications of a specific indicator is not expected to have causal effect on the latent variable.

Formative model defines a composite variable, known as the latent variable that summarizes the common variation in a collection of indicators. The indicators that compose the latent variable are considered to be independent variables to the latent variable. The causal action flows from the independent variables (indicators) to the latent variable (Diamantopoulos et al., 2008)

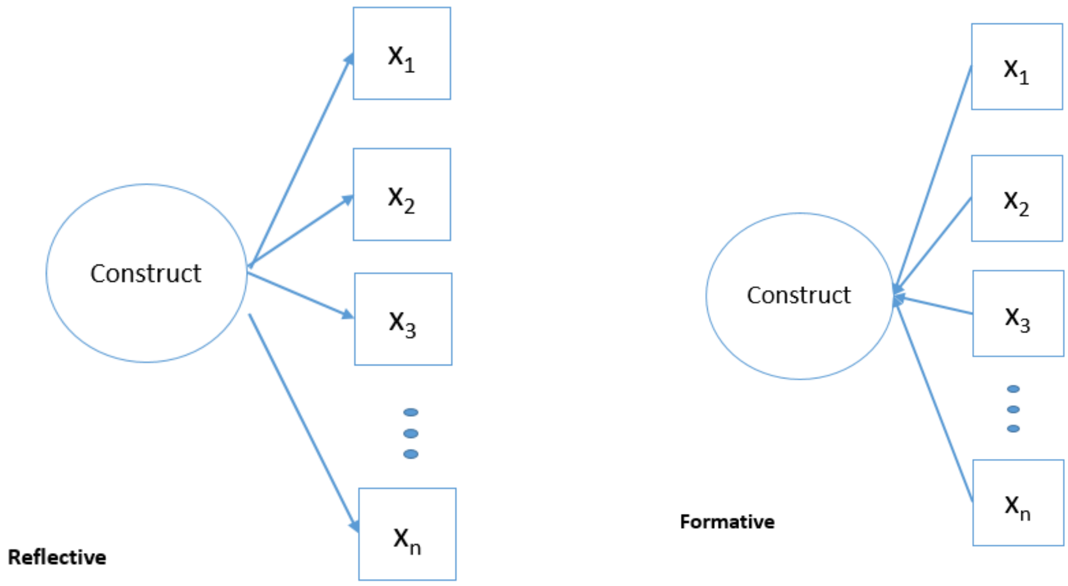

Figure 15 Measurement models of SEM

The specification of the formative measurement model is described in Equation :

$$\eta = \sum_{i=1}^{n}(\gamma_i\, x_i\ ) + \zeta \qquad (9)$$

Where γ_i is a coefficient that reflects the effect of indicator xi on the latent variable η, ζ being a disturbance term (Diamantopoulos et al., 2008).

There are a number of software programs to build and test SEM models. The evaluation of the cases considered in this thesis was performed by the AMOS software, an added SPSS module . AMOS is a statistical software and it stands for analysis a moment structures. It is also known as analysis of covariance or causal modeling software. 5.2.2 SEM Literature review.

Examining related literature, SEM has been applied in various fields. Teo (Teo et al., 2013) adopted SEM technique in education, providing a non-mathematical introduction and Beran (Beran and Violato, 2010) adopted SEM in medical and health science. Guo (Guo et al., 2008) examined how SEM is used in social work research and the extent to which it reflected best practices.

SEM was applied in cloud environment. Gangwar (Gangwar et al., 2015) integrated TAM model and TOE framework for cloud computing adoption at organization level. A conceptual framework was developed, using technological and organizational variables of TOE framework, as external variables of TAM model whereas, environmental variables were proposed to have direct impact on cloud computing adoption. Data were derived from 280 companies by filling a questionnaire. The data were analyzed using exploratory and confirmatory factor analyses. Further, structural equation modeling was used to test the proposed model.

Furthermore, Raut (Raut et al., 2018) proposed a hybrid three-stage Structural Equation Modeling (SEM) - Artificial Neural Network (ANN) - Interpretive Structural Modeling (ISM) approach, together abbreviated as the SEANIS for analyzing the factors influencing cloud computing adoption services in the context of Indian private organizations. This study extended Technology Organization Environment (TOE) model by adding new determinants, such as risk analysis and perceived IT security risk. The data were collected from the industry experts and were analyzed by SEM and ANN approaches. The output of SEM revealed that trust, management style, technology innovation, risk analysis, and perceived IT security risk exercised a significant influence on cloud computing adoption. The SEM results were considered as inputs for the ANN approach and ISM methodology. The results of ANN indicated that perceived IT security risk, trust, and management style hold a leading role in cloud computing adoption.

In addition, Isaias (Isaias et al., 2015) examined European organizations' awareness of cloud computing and sustainability opportunities and risks. Data were collected through online survey of 56 Information Technology managers in Europe. A SEM model was developed for evaluating the survey results and the output of the model confirmed that even though cloud computing enhanced ICT technology, issues such as security, privacy and risks are still a major concern and challenge of cloud adoption.

Gupta (Gupta et al., 2013) presented five factors that influence IaaS services adoption by SMEs business community. Structural Equation Model was adopted for the evaluation of the model and according to the output of the model ease of use and convenience is the biggest favorable factor, followed by security and privacy and then comes the cost reduction. Cloud reliability had a minor importance, because SMEs do not consider cloud reliable. Furthermore, SMEs do not prefer to use cloud for sharing and collaboration, since they prefer their old conventional methods for sharing and collaboration with their stakeholder.

Amornkitpinyo (Amornkitpinyo and Piriyasurawong, 2017) synthesized and designed a mobile cloud learning acceptance for higher education students by also using SEM method. Basic Digital Literacy, Social Cloud, Satisfaction, Information Quality, TAM Model and Actual Use were selected for the construction of the research model.

Park (Park and Kim, 2014) identified and examined the factors that contribute to shaping user perceptions toward mobile cloud computing services by integrating these factors with the technology acceptance model. A structural equation modeling analysis was applied on data collected from 1099 survey samples, and results revealed that user acceptance of mobile cloud services was largely affected by perceived mobility, connectedness, security, quality of service and system, and satisfaction.

Finally, Chen (Chen et al., 2018) constructed research competing models (RCMs) and determined the best-fitting model for understanding industrial organization's acceptance of cloud services. This work integrated the technology acceptance model and the principle of model parsimony to develop four cloud service adoption. SEM technique was used and the data collection was based on a survey of 227 firms in Taiwan. The results pointed out that, although all four RCMs had a high goodness of fit, research competing model A (Model A) demonstrated superior performance and was the best-fitting model.

5.3 Proposed Pricing SEM-oriented model

Cloud providers set the pricing policies, increasing the number of the users who seek cloud solutions that fulfill their technical requests at the possible lowest cost. Based on Figure 12, a hierarchical model that examines the providers' aspect about cloud pricing, is proposed and implemented. The model defines and analyzes the functional and non-functional categories. Three conceptual levels were considered; the first level represents the price of cloud services, the second level a number of categories are defined and each category corresponds to an important aspect, which is described by attributes that constitute the third level of the hierarchy. An attribute is an indicative feature that characterizes a category (e.g. CPU type is an attribute of the performance category). Figure 16 presents the proposed model, whereas the details about the functional and non-functional categories and their corresponding attributes were presented in the previous section.

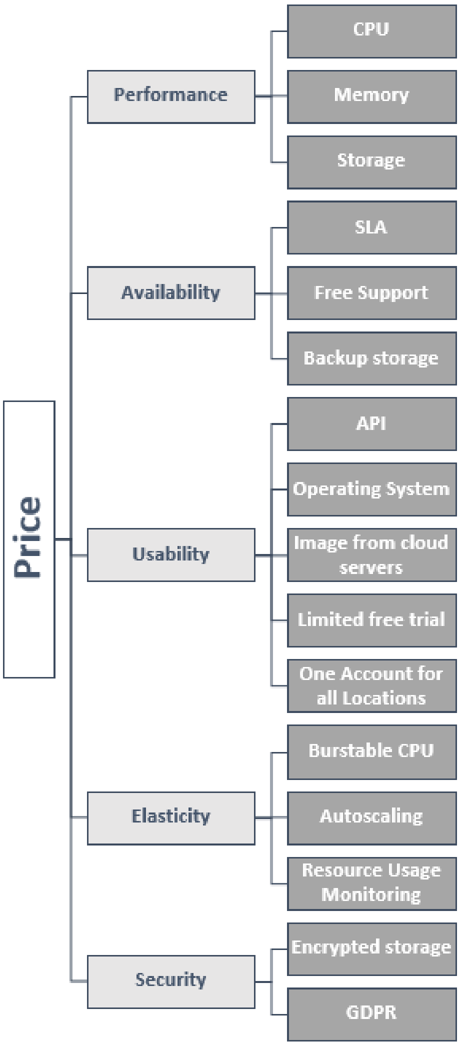

Figure 16 The proposed hierarchical model for analyzing the functional and non-functional of IaaS.

A number of eight hundred six (806) cloud bundles were collected by Cloudorado for the implementation of the proposed model, corresponding to a number of twenty three (23) providers, as shown in Table 11. In addition Table 15presents the IaaS functional characteristics.

Functional Features	Values
vCPU	1x, 2x, 4x, 8x, 16x,32x
RAM(GB)	2, 4, 8, 16, 32, 64, 128, 256,
Storage (GB)	50, 100, 200, 500, 1000, 2000, 5000, 10000

Table 15 IaaS functional characteristics.

Structural Equation Model analyzes the relations between price and the functional and non-functional categories. Latent variables correspond to the categories of Figure 16 and the indicators are the cloud attributes. The indicators of the non-functional attributes are treated as categorical variables, whereas the indicators that describe the functional features are characterized as numerical variables.

Table 16 introduces the latent variables that represent non-functional requirements with their corresponding indicators and values whereas Table 17 introduces the latent variable, defined by functional indicators.

Latent Variables	Indicators	Level Scale	Values
Security	Encrypted Storage	2	Yes/No
	GDPR	2	Yes/No
Availability	SLA Level	5	1:99.90%, 2:99.95%, 3:99.98%, 4:99.99%,
	Backup Storage	2	Yes/No
	Free Support	2	Yes/No
Elasticity	Burstable CPU	2	Yes/No
	Auto-scaling	4	0:None, 1:Vertical, 2:Horizontal, 3:Both
	Resource usage Monitoring	2	Yes/No
Usability	API	2	Yes/No
	One Accountfor All Locations	2	Yes/No
	Image from Cloud Server	2	Yes/No
	Limited Free Trial	2	Yes/No
	Supported Operating System	2	Linux/Windows

Table 16 Latent variables, non-functional attributes and their corresponding values.

Latent Variables	Indicators
Performance	CPU
	Memory
	Storage

Table 17 Latent variables and functional attributes

The SEM based model is described by a path diagram, which is a fundamental model of SEM, since it depicts the causal model and it also constitutes a comprehensive representation of the relations among the latent, observed and indicators variables. In the proposed pricing model, the path diagram represents the relations between price and latent variables and the relations between latent variables and their corresponding indicators. The proposed SEM based model examines the provider perspective and accomplishes to point out the functional and non-functional categories that mainly determine the final cloud price.

The corresponding path diagram is depicted in Figure 17, incorporating the assigned relation weights of the cloud attributes. But before conducting the analysis of the results, the Cronbach's alpha descriptives have been estimated, assessing the reliability and the internal consistency of each individual latent variable and of the whole dataset, as shown in Table 18.

Latent Variables	Number of Indicators	Cronbach's Alpha descriptives
Performance	3	0.804
Availability	3	0,781
Security	2	0.719
Elasticity	3	0.779
Usabilty	5	0.734
Total Dataset	17	0.751

Table 18 Cronbach's alpha descriprives

The threshold of this measurement is above 0.70, therefore all the values of the collected dataset are acceptable (Cronbach, 1951). In addition, goodness of fit was estimated, aiming to investigate the stability of the SEM model (Hair et al., 1998). The comparative fit index (CFI), the Root Mean Square Error of Approximation (RMSEA) index, the Tucker -Lewis index (TLI) and Goodness fit index (GFI) were also estimated validating the SEM model. According to the relative literature, TLI and CFI have an acceptable threshold for values greater than or equal to 0.9 (Browne and Cudeck, 1993). In addition, RMSEA should not be greater than 0.05 and finally GFI should be over 0.90 (Hair et al., 1998, Bagozzi and Yi, 1991, Browne and Cudeck, 1993) Table 19presents the estimated statistics indexes

Goodness of fit indexes	Values	Threshold
CFI	0.965	> 0.9
TLI	0.923	> 0.9
RMSEA	0.045	< 0.05
GFI	0.925	> 0.9

Table 19 Goodness of fit indexes.

5.4 Results of SEM-oriented model

Figure 17 indicates the categories that influence price and highlights the impact of the cloud attributes on the corresponding category. The path analysis indicates that performance, which is based on functional attributes, is the leading regulator in the determination of price. However, the output of the model points out that the overall contribution of non-functional attributes in the shaping of the price outperforms to functional attributes influence.

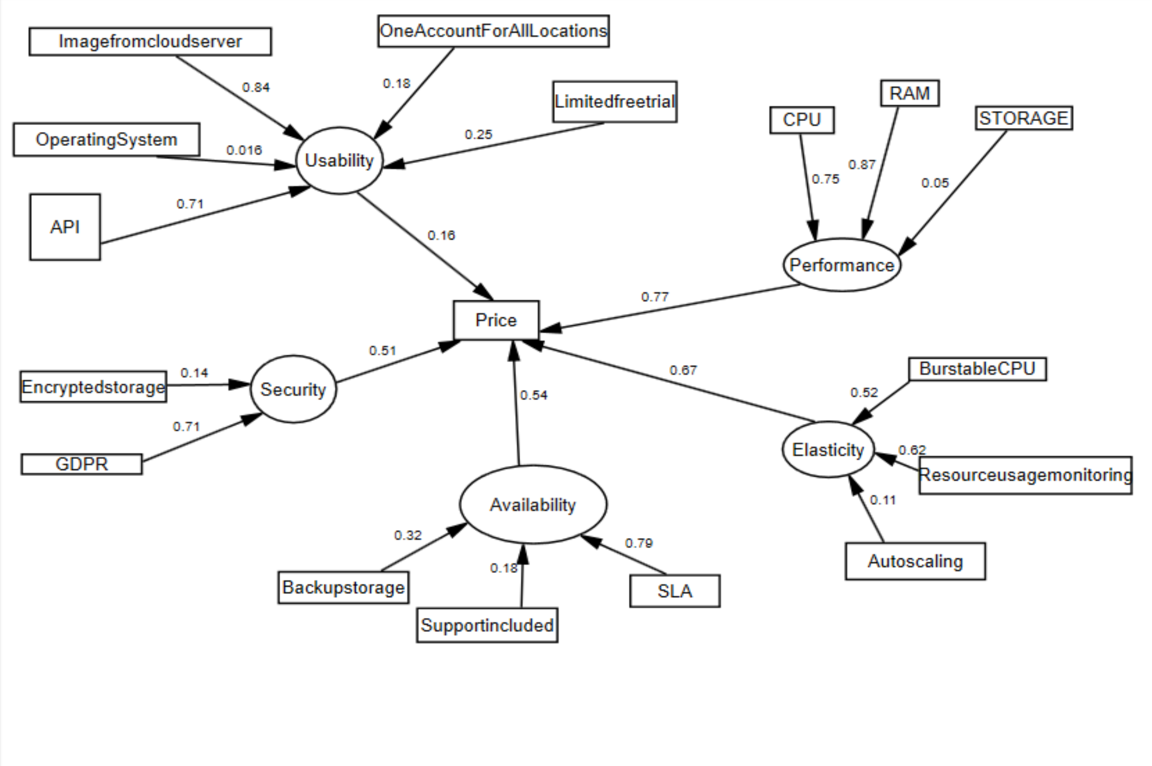

Figure 17 Output of SEM based model.

Therefore, it appears that performance is the most significant category influencing the price with a weight of 0.77. It is rather justifiable, that the pricing policy of the cloud providers is largely dependent on performance attributes, since the user can easily understand them, and is therefore willing to pay. Performance, as described by memory, storage and CPU, reflects providers' commitment for handling demanding workloads. According to Figure 17, RAM is the indicator with the higher impact (0.87) on Performance and CPU is highly rated as well since it determines how fast you can perform tasks. RAM and CPU are significant components of a VM and highly influence the performance of the VM. RAM's capacity affects the speed of a VM and is also one of the easiest and most effective ways to boost a VM's performance by using additional RAM. Moreover, a faster processor can run specialized software and manage a greater number of workloads. For that reason, providers focusing on RAM and CPU offer powerful cloud services that fulfill users' demanding requirements and at the same time increase their market share.

Elasticity is also a significant category with an estimated weight 0.67. It is also not surprising that elasticity is highly related with the service price, since it represents the ability of the cloud to handle bursts of workloads. In addition, examination of the relations among Elasticity and the contributed attributes, leads to the result that Resource Usage Monitoring is essential as it ensures capacity, workload management and evaluates the performance of IaaS services, which justifies its significant impact on Elasticity (0.62). Moreover, Burstable CPU is also strongly related to Elasticity as cloud providers aim to fulfill users demanding requirements for CPU flexible solutions. The providers, therefore, offer cloud instances, enabling Burstable CPU and providing a baseline level of processing speed, taking into account that in case of CPU increment additional processing power is offered. Finally, the auto scaling attribute seems to have a minor impact on Elasticity.

Furthermore, Availability is also a dominant category with a weight 0.54. Availability is strong related with cloud SLA (0.79), revealing that that in the competitive cloud market, providers aim to offer high availability at extra charge, in order to increase their market share, since SLA serves as the warranty of cloud services. SLA is a critical component of any cloud provider contract as it describes the uptime SLA level expressed in percentage points of availability and it commits the cloud providers to maintain their services up in, all within contract limits. As a consequence, cloud providers consume additional computing resources with extra charge in order to be reliable to their clients. Backup storage and Support features follow with minor impact on Availability. Backup storage has an impact on Availability (0.32), pointing out that providers invest in customers' satisfaction by ensuring effective cloud solutions for avoiding data loss, whereas support has a minor contribution to Availability since providers offer a basic support without extra charge and any additional support is charged

Security has an essential impact on price with a weight 0.51, reflecting the importance of security in cloud market (So, 2011). Examining the security indicators, GDPR has been developed in order to prevent private organizations within the European Union, which store customer data from accidentally disclosing or losing personal information(Ibrahimi, 2017). Into this context, the cloud vendors consider these principles the main dominant attribute of security, with an estimated weight of 0.72, whereas encrypted storage has a minor impact on security.

Usability seems to be the latent variable with low impact on price, since the corresponding services are well-established and offered by the majority of cloud providers. Focusing on Usability attributes, Image from Cloud server appears to be the main adjuster of price, as providers offer a convenient feature that helps end users to copy the overall state of a server in the cloud. In addition, API, the core component behind any cloud service, is highly related to price, as it enables effective cloud management through applications and mobile devices. API reinforces the user-friendliness of IaaS services and constitute the cloud as a flexible environment. The remaining attributes of usability have a minor impact on price.

5.5 Conclusions Structural Equation Model is adopted for the development of a pricing model which highlights providers' aspect and points out the functional and non-functional categories and their corresponding impact on cloud price. The cloud bundles used for the construction of the SEM-based model were derived from Cloudorado platform. The collected bundles were derived from 23 providers that fulfill specific criteria. The output of SEM model reveals that performance highly contributes to the shaping of price, elasticity, availability and security follow and finally usability appears to have a minor impact on price. The estimated weights of the non-functional attributes are highly significant, therefore the output of the proposed model captures the essential role of the non-function categories in pricing a cloud price. Furthermore, the impact of each indicator on the corresponding latent variable has been estimated, indicating the leading indicators of each category. Regarding performance category the RAM highly influence performance category, also resource usage monitoring is the leading indicator of elasticity. Focusing on Availability, SLA is the dominant indicator, whereas GDPR has a great impact on security. Finally, image from cloud server appears to hold the most important role to the construction of the usability.

Chapter 6 Efficiency of cloud providers- A DEA approach

6.1 Outline

IaaS model is not a new technology but rather a different way of contracting for services and technologies. However, it can be complex, fragmented and confusing for potential clients. Cloud users mainly select IaaS services that offer the best value for money in cloud environment. Value for money is not based only on the minimum purchase price but also on the maximum efficiency and effectiveness of the purchase.

Cloud efficiency depicts the cost-effectiveness of cloud services, assisting end users to choose not only an advantageous cloud solution but also the most cost-effective cloud solution. Therefore, in this section the relation between the efficiency and pricing of service is examined, taking into consideration the functional and non-functional attributes. The analysis is based on the Data Envelopment Analysis (DEA) approach.

6.2 DEA background

Data Envelopment Analysis (DEA) is a nonparametric method, focusing on performance evaluation and it has been widely studied, used and analyzed gaining increasing popularity among researchers. Even though DEA is strongly connected with production theory in economics, this tool is also applied for benchmarking the performance of services (Wikipedia). The method was originally introduced by Charnes, Cooper and Rhodes (Charnes et al., 1978) in 1978, as a mathematical programming model to evaluate non-profit and public sector organizations. Data envelopment analysis (DEA) has been successfully used for assessing the comparative efficiencies of decision-making units (DMUs; e.g. banks, schools, hospitals, factories, etc.), especially when the presence of multiple inputs and outputs makes comparison with other techniques difficult (S. Kumar, 2014, Sherman and Zhu, 2006, Braglia and Petroni, 1999)

DEA method estimates relative efficiency, which is defined as the ratio of output to input: the more the output per unit if input achieved, the greater the relative efficiency is. In more complicated situations, such as the environment of cloud computing, this kind of measure is usually insufficient. This is due to the existence of multiple outputs and inputs related to different resources and due to the numerous DMUs being evaluated which are only relatively homogeneous and cannot be easily analyzed (Sherman and Zhu, 2006). Therefore, it is obvious that DEA is a vital tool in evaluating that efficiency of various units or producers and also estimates efficiency without taking into consideration the form of the production function or the weights for the selected inputs and outputs (Braglia and Petroni, 1999).

This linear based multi-criteria decision making methodology develops a function whose form is determined only by the optimal units and compares each unit with them. The results of this methodology point out not only the most efficient units but also the inefficient ones. Furthermore, the DEA focuses on the inefficient units indicating modifications that can be made aiming to efficiency enhancement.

Finally, the DEA method identifies a frontier that can be used as a reference for efficiency calculations. The frontier is a point method that assumes that if a business can produce a certain level of output, utilizing specific input levels, other similar firms should be able of doing the same and estimates its relative efficiency (Wikipedia).

A common calculation for relative efficiency of a many input–many output DMU is the following:

$$Efficiency = \frac{weighted\ sum\ of\ outputs}{weighted\ sum\ of\ inputs} \quad (10)$$

which, after introducing the usual notation for a DMU with *m* outputs and *n* inputs, can be written as:

$$Efficiency\ of\ DMU\ j = \frac{u_1 y_{1j} + u_2 y_{2j} + \ldots + u_m y_{mj}}{v_1 x_{1j} + v_2 x_{2j} + \ldots + v_n x_{nj}} \quad (5)$$

where u_r is the weight given to output r, v_i is the weight given to input i, y_{rj} is the amount of output r from DMU j and x_{ij} is the amount of input i in DMU j.

According to the above equations, the measurement of the relative efficiency of a DMU, with multiple possibly inputs and outputs, is achieved by constructing a hypothetical efficient unit, as a weighted average of efficient units, to act as a comparator for any other unit (Emrouznejad).

In some cases it is difficult to value the inputs and outputs of a DMU, while at the same time units may value their inputs and outputs in a different way and therefore adopt different weights. Thus, the assumption of setting universally valid weights is unsatisfactory and DEA gives a solution to this problem by determining a set of weights in the most favorable light for each DMU in comparison to other units. Efficiency (h0) of a specific target unit (j0) can be obtained as a solution to the following problem (Sherman and Zhu, 2006, Braglia and Petroni, 1999, Emrouznejad)

(M1)

$$\max h_0 = \frac{\sum_r u_r y_{rj_0}}{\sum_i v_i x_{ij_0}} \quad (6)$$

subject to:

$$\frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}} \le 1, \quad \textit{for each DMU } j = 1, 2, \ldots, k \quad (7)$$

$$u_r, v_i \ge \varepsilon, \quad r = 1, 2, \ldots, m \quad i = 1, 2, \ldots, n \quad (8)$$

The variables of the above problem are the weights (u, v) which are the most favorable to unit j_0, as compared to the other k-1 DMUs, meaning that DEA determines the weights to calculate the efficiency (h_0) based on assumption that more of outputs and less of inputs are desirable, so that DMU j_0 looks as efficient as possible. Each unit is allowed to adopt a set of weights in the most favorable light in comparison with the other units. The weights (u, v) are bounded to be greater than, or equal to, some small positive arbitrary quantity ε in order to avoid any input or output being totally ignored. The relative efficiency of each DMU is subject to the constraint that no unit can be more than 100% efficient when the same weights are applied to each DMU, meaning that the efficiency is bounded to be lower than or equal to 1 (Charnes et al., 1978).

Model M1 is fractional linear programming which first needs to be converted into a linear form in order for the methods of linear programming to be applied. The linearization process is relatively straightforward and the linear version of the constraints of M1 is shown in the following model M2 (Charnes et al., 1978, Sherman and Zhu, 2006).

$$\max \mathrm{h}_0 = \sum_r u_r y_{rj_0} \qquad (11)$$

subject to:

$$\sum_i v_i x_{ij_0} = 1 \quad (12)$$

$$\sum_r u_r y_{rj} - \sum_i v_i x_{ij} \le 0, \quad for\, each\, DMU \;\; j = 1, 2, \ldots, k \quad (13)$$

$$u_r, v_i \ \ge \varepsilon, \quad r = 1, 2, \ldots, m \quad i = 1, 2, \ldots, n. \quad (14)$$

(M2)

Considering, the maximization of a fraction, the most important point is the relative magnitude of the numerator and denominator and not their individual values. In other terms, there would be the same result if the denominator is set equal to a constant and the numerator is maximized. The relative efficiency of the target unit can be obtained by solving model M2. The efficiencies of the entire set of DMUs can be measured by finding the solution to the linear program focusing on each unit in turn (Emrouznejad).

There are two types of DEA models. The first is called multiplier model – the primal model, which was previously described. The other is called envelopment model – the dual model. The dual model is constructed by assigning a variable (dual variable) to each constraint of equations (9) to (12) in the primal model (model M2) and then formulating a model on these variables, as described in detail in (Emrouznejad, LtdCompany.). This procedure results in the following model M3, where h_0* is the efficiency score of a target unit (j0) that would result in the optimum (calculated, e.g., by splitting the sample):

$$h_0^* = \min h_0 \quad (15)$$

subject to

$$\sum_j \lambda_j x_{ij} \le h_0 x_{ij_0}, \quad i = 1, 2, \ldots, n \quad (16)$$

$$\sum_j \lambda_j y_{rj} \ge y_{rj_0}, \quad r = 1, 2, \ldots, m \quad (17)$$

$$\sum_j \lambda_j = 1 \quad (18)$$

$$\lambda_j \ge 0, \quad j = 1, 2, \ldots, k. \quad (19)$$

(M3)

The solution to either the original LP (the primal) or the partner (the dual) provides the same information about the problem being modelled. The solution to the dual model seeks to minimize the efficiency with values of λ_j to form a composite unit with inputs $\sum_j \lambda_j x_{ij}$, i=1, 2, … n and outputs $\sum_j \lambda_j y_{rj}$, r=1 ,2 ,… ,m more efficient than unit j_0 which is being evaluated. More specifically, the weighted sum of the inputs of the other DMUs should be less than, or equal to, the inputs of unit j_0 and the weighted sum of the outputs of the other DMUs should be greater than or equal to unit j_0. The weights are the λ values. All of the other DMUs with non-zero λ values are the units against which each inefficient DMU was found to be most directly inefficient (Sherman and Zhu, 2006, Emrouznejad)

In addition, there are two approaches to apply the DEA model. The input-oriented approach aims to increase the efficiency of a DMU by minimizing inputs while keeping outputs fixed at the same level. On the other hand, the output-oriented DEA model is used when outputs are maximized, while keeping the input level as fixed as possible. The input oriented approach was applied into the context of this thesis, while proposing an alternative methodology for the selection of IaaS cloud computing services. This is achieved by applying DEA to a multi-attribute decision-making problem, where each performance may depend on a number of functional and non-functional factors. Such a selection is difficult, due to the many qualitative features that are continuously being offered together with IaaS bundles. In this way, cloud bundles of services can be selected, not just according to the price but also based on the importance that each non-functional requirement has for the users

Focusing on the relative literature there are several proposed schemes that discuss cloud efficiency of IaaS service. However, the current thesis has developed an innovative approach, filling a gap in literature by pointing out the crucial impact of both functional and non-functional attributes on cloud efficiency.

6.2.1 Relative Literature

Brebner (Brebner and Liu, 2010) and Liu modeled cloud service efficiency, predicting the resource requirements in terms of cost and performance. Cloud services from Google App Engine, Amazon EC2 and Windows Azure were used and their paper pointed out that performance was directly related with the type, the cost and constrains of cloud applications.

In addition, Ostermann and Iosup (Iosup et al., 2011) examined the performance analysis of cloud computing services for Many-Tasks Scientific Computing. They presented an empirical evaluation of the performance of four cloud computing providers including Amazon EC2. Using simulation, they compared performance and cost models of each cloud provider.

Kandula (Li et al., 2011a) examined a comprehensive comparison of four public cloud providers based on efficiency. The performance was described by metrics that characterize efficiency of cloud providers.

Kumar (S. Kumar, 2014) classified cloud services based on efficiency, embodying price to the ranking. This model assisted end users to select the optimal cloud solution but it also helped providers to enhance their services. For the calculation of the efficiency Data Envelopment Model (DEA), Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) model were used.

Xu (Xu et al., 2015) described cloud services based on functional requirements (CPU, Memory and Storage) DEA was applied on a limited dataset of cloud bundle.

6.3 DEA and Categorical Variables.

Inputs and outputs of a DEA model are usually quantitative but in the context of the present work, it is necessary to import qualitative variables, such as ordinal or nominal variables. This is accomplished by defining dummy/categorical variables, depicted by numbers for order or identifiers for names. The DEA model uses categorical variables to describe ordered variables (i.e. of the type "low", "medium", "high") but also variables that take on only a finite number of values, that are inputs or outputs of certain types and cannot be represented by continuous variables. DEA categorical variables operate as further constraints on making comparisons between subsets of comparable DMUs. (Førsund, 2001, Banker and Morey, 1986, Löber and Staat, 2010). The quantitative variables of the current thesis were analytically introduced in the previous section.

Methods of embodiment categorical variables to a DEA model have been examined but they have been applied in a few cases. Charnes in (Charnes et al., 1981) has proposed a solution for the incorporation of categorical variables in DEA model, however his solution was slow for the model because, a separate DEA runs for each distinct combination of categorical variable.

Even though methods of incorporating categorical variables to a DEA model have been introduced before, they have been rarely applied from researchers. Löber and Staat (Löber and Staat, 2010) try to embody categorical variables in DEA models and their proposal can be implemented by any common DEA software. Towards this direction, in the context of the present work their approach was applied and developed using the proposed DEA-oriented model using the Maxdea (LtdCompany.) freeware software.

The proposed DEA model constitutes an input-oriented model with non- discretionary inputs. The input of the model must be grated than 0 for the DMU to be excluded from reference sets of other DMUs and equal to 0 for the DMU to be evaluated.

For an input-oriented model with non-discretionary inputs/indicators, each input indicator must be greater than 0 for the DMU to be excluded from reference sets of other DMUs and equal to 0 for the DMU to be evaluated. Categorical variables must not change the efficiency score for any DMU, for which the referent point in a model without the additional constraint had already been composed of peers from categories not better than its own (Löber and Staat, 2010, Charnes et al., 1981). The following LP represents a general solution for an input-oriented model with *P* inputs *x* and *Q* outputs *y* for *N* DMUs indexed by *n*. The model is based on indicator variables and is mathematically explained in detail in (Löber and Staat, 2010), where it finally ends up in the following Model M4. The true efficiency score ϑ for a DMU (x_0, y_0) with *R* categorical variables with C_r categories is:

$$\min \theta \qquad (20)$$

subject to:

$$\sum_{n=1}^{N} \lambda_n y_{qn} \geq y_{q0}, \quad q = 1, \cdots, Q \qquad (21)$$

$$\sum_{n=1}^{N} \lambda_n x_{pn} \leq \theta x_{p0}, \quad p = 1, \cdots, P \qquad (22)$$

$$\sum_{n=1}^{N} \lambda_n i_{rn}^{C_r} \leq \theta i_{r0}^{C_r}, \quad r = 1, \ldots, R, C_r = 1, \ldots, C_r - 1 \qquad (23)$$

$$\lambda_n, x_{pn}, y_{qn} \geq 0, \quad n = 1, \ldots, N \qquad (24)$$

(M4)

To exclude DMUs in a better category as peers in referent points for DMUs in a lower category, indicator i_{rn} must be equal to x_{pn}, where x_p can be either one of the *P* inputs (clearly redundant, whichever one is chosen) for all DMUs in a lower category and must be equal to 0 for all other DMUs

6.4 Development of the DEA-oriented pricing model

According to the previous chapters, the non-functional attributes have an essential and crucial role in the pricing of a service. Based on this concept, the DEA methodology was adopted in order to explore the role of the functional and non-functional attributes in cloud performance, through an economic aspect. Therefore, the price of cloud bundles was also considered as a variable, capturing the cost-effectiveness of cloud services. The proposed model also evaluates numerous equivalent cloud services across different providers in an objective perspective.

DEA, apart from estimating the relative efficiency and pointing out the efficient DMUs, also focuses on inefficient DMUs, offering possible changes in the participated variables, seeking to reach the efficient frontier. Therefore, the proposed pricing model based on DEA is implemented over numerous IaaS bundles, aiming to estimate their relative efficiency and examine the inefficient bundles. DEA was developed using two different datasets. Initially, it was applied over cloud bundles exclusively described by functional attributes and price. Then, the proposed model is applied over cloud bundles that include functional and non-functional attributes. The comparison of the two cases points out the key role of non-functional in the relative efficiency.

Data collection was based on Cloudorado and the collected IaaS cloud bundles were categorized into three groups

- ***Computation Optimized Instances*:** Instances for compute-bound applications that feature high performance processors.
- ***Memory Optimized Instances***: Instances for memory-intensive applications
- ***Storage Optimized Instances***: Instances that are designed for applications that require high sequential read and write access to very large data sets on local storage (2018a)

The classification of cloud instances in the above three groups is introduced by Amazon EC2 . Amazon is the leading provider of cloud infrastructure services, as it maintains a significant share in the cloud market. Therefore, the categorization Amazon follows is considered to be the most appropriate pattern. The total number of the collected price bundles is 806, coming from 23 providers. The number of compute, memory and storage optimized instances are 401, 205, 200, respectively. The collection of cloud bundles was based on criteria that were not fulfilled by all cloud providers, thus the number of the collected price bundles of each provider differs. Table 11 presents the cloud providers that fulfill the specific requirements.

The collected cloud instances are described by functional properties (CPU, memory, storage) shown in Table 20, Table 21, Table 22 respectively, together with the considered values.

vCPU	Mem(GB)	Storage(GB)

1	2	50
2	4	100
4	8	100
4	8	200
8	16	200
8	16	500
16	32	200
16	32	500
16	32	1000
32	64	500
32	64	1000
32	64	2000

Table 20 Compute optimized instances

vCPU	Mem(GB)	Storage(GB)
2	8	50
2	16	50
2	16	100
4	32	100
8	64	200
16	128	500
32	256	1000

Table 21 Memory Optimized Instances

vCPU	Mem(GB)	Storage(GB)
2	16	500
2	16	1000
4	32	1000
4	32	2000
8	64	2000
8	64	5000

16	128	5000
16	128	10000
32	256	10000

Table 22 Storage Optimized Instances

The DEA methodology is applied over a multi-attribute decision-making problem, where each performance may depend on a number of functional and non-functional factors. Therefore, end-users can choose the optimal and cost-effective solution, based on the price and the estimated relative efficiency, which is indicated by the output of DEA-oriented model (Jeong, 2013, Arias, 2013)

As shown in Figure 12, IaaS cloud attributes (functional and non-functional) constitute the pricing factors that determine the price of cloud bundles and contribute to the estimation of the relative efficiency. Functional attributes are numerous variables, whereas non-functional attributes are treated as categorical variables for the input-oriented DEA model (Löber and Staat, 2010). Based on the corresponding literature (Glinz, 2007, Arias, 2013), non-functional aspects, such as security, availability, elasticity and performance, are presented in Figure 12. The cloud attributes with the corresponding values that constitute these aspects are described in Table 23.

CLOUD FEATURES	NUMBER OF CATEGORIES	VALUES
	SECURITY	
Encrypted Storage	2	YES/ NO
Safe Harbor / EU Directive 95/46/EC	2	YES/ NO
	AVAILABILITY	
SLA Level	5	1:99.90%, 2:99.95%, 3:99.98%, 4:99.99%, 5:100%
Backup Storage	2	YES/ NO
Free Support	2	YES/ NO
	ELASTICITY	
Burstable CPU	2	Burstable/ Fixed

Auto-scaling	4	0:None, 1:Vertical, 2:Horizontal, 3:Both
Resource usage Monitoring	2	YES/ NO
USABILITY		
Web Interface	2	YES/ NO
API	2	YES/ NO
One Account for All Locations	2	YES/ NO
Image from Cloud Server	2	YES/ NO
Limited Free Trial	2	YES/ NO
Supported Operating System	2	LINUX/WINDOWS

Table 23 Functional and non-functional features of cloud bundles of services treated as dea categorical variables with corresponding values

The majority of the non-functional indicators are described by a two-level scale “YES” or “NO”, while there are two indicators with different number of levels. A 5-level scale is used for SLA- Level because the corresponding value varies from 99.90% to 100%. In addition, auto-scaling indicator is denoted by a 4 level-scale, because there are two different types of this attribute. Level 1 and Level 2 describe vertical and horizontal auto-scaling, respectively. Vertical auto-scaling refers to a server which is automatically upgraded by adding more resources (i.e. RAM, storage), while more servers are added according to workload requirements through horizontal auto-scaling. Level 0 denotes that auto-scaling is not supported by cloud provider in contrast with Level 3 which defines that both vertical and horizontal auto-scaling are offered. The supported operating system indicator may be a functional attribute but it is considered as a non-functional feature treated as a categorical variable. It is described by a 2-level scale with corresponding values Linux and Windows.

6.5 DEA Evaluation

The proposed model estimates the relative efficiency, based on Data Envelopment Analysis and presents an input-oriented model, described by DMUs, inputs and output parameters. The importance of this model lies in maximizing the efficiency rates by reducing inputs and maintaining outputs at the current level.

As shown in Figure 18 the non-functional attributes, treated as categorical variables together with price constitute the inputs of the proposed model, whereas functional attributes define its outputs.

Price defines the annual subscription and is chosen as an input parameter. It is a multidimensional factor because a provider who is considered to be the cheapest for one cloud instances category might be the most expensive for another.

Functional attributes, such as memory (GB), storage capacity (GB) and compute power (cpu cores) are defined as the outputs of the DEA-oriented model. The Cloudorado platform includes a few more attributes, such as Time On, Transfer In, Transfer OUT, together with the option that the CPUs, RAM and the storage can be distributed among more than one physical server, participating in the price bundling of Cloudorado. According to the hedonic model introduced in a previous section, Transfer In (the number of bytes received by server from the internet per month) and Transfer Out (the number of bytes sent by server to Internet per month) have a minor impact on pricing, thus they were excluded from the proposed model. Therefore and with no loss of generality, the Transfer In attribute was considered to be at 1GB and the Transfer Out at 10GB per month. As far as Time On is concerned, this was set at a level of 100% availability per day and the default offered value of non-distributed resources was also considered.

Figure 18 illustrates the input-oriented model with all input and output parameters.

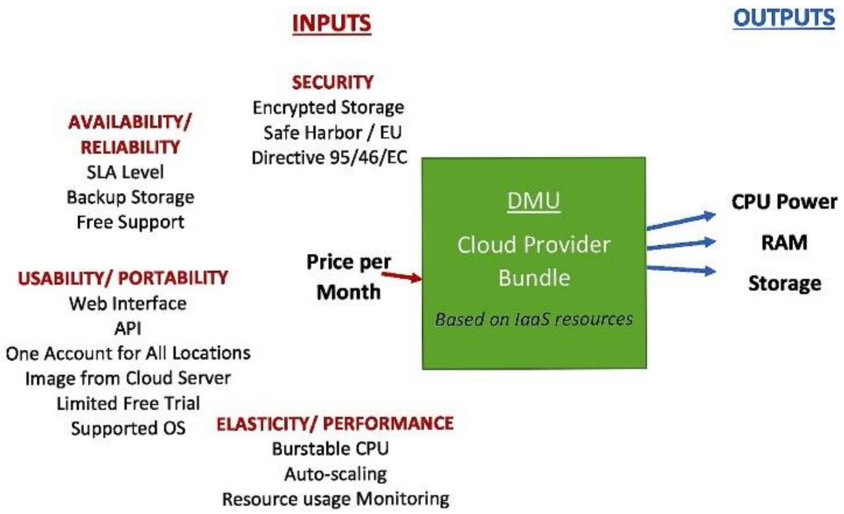

Figure 18 The proposed input-oriented DEA model with all input and output parameters.

All categorical variables are used as input indicators, since the present DEA model is an input-oriented model with *P* inputs *x* and *Q* outputs *y* for *n* DMUs, indexed by *i*. Therefore, each categorical variable, from *R* categorical variables in total, has a number of categories *Cr*, as shown in Figure 18. A corresponding number of binary dummies of the type proposed by Banker and Morey (Banker and Morey, 1986), is generated in this way, *Cr-1*. Hence, these variables are necessary and are designed to be multiplied with the price of each bundle that constitutes the input of the DEA model, thereby creating *Cr-1* input indicators in order to achieve the desired result.

The objective function of the input-oriented model, subject to the constraint on the indicators z_{ri} is given below, where ϑ^* is the efficiency score that would result in the optimum:

$$\theta^* = \min \theta \quad (25)$$

subject to:

$$\sum_{i=1}^{n} \lambda_i y_{qi} \geq y_{q0}, \quad q = 1, \cdots, Q \quad (26)$$

$$\sum_{i=1}^{N} \lambda_i x_{pi} \leq \theta x_{p0}, \quad p = 1, \cdots, P \quad (27) \qquad (M5)$$

$$\sum_{i=1}^{N} \lambda_i z_{ri}^{C} \leq \theta z_{r0}^{C}, \quad r = 1, \ldots, R, C = 1, \ldots, Cr - 1 \quad (28)$$

$$\lambda_i, x_{pi}, y_{qi} \geq 0, \quad i = 1, \ldots, N \quad (29)$$

As mentioned above, cloud bundles, services were grouped into compute, memory and storage oriented instances and the proposed model is applied over each group returning the most efficient services. In the case of compute optimized instances there are 401 DMUs, 205 DMUs for the memory-oriented group and, finally, 200 DMUs correspond to the storage optimized instances.

The evaluation of the model was based on MaxDEA (LtdCompany.), a user-friendly software, with no limitation on the number of DMUs. The efficient cloud bundles are indicated and also the rate of the inefficient bundles is estimated. In addition, DEA calculates the slacks that are defined as the additional improvement needed for an inefficient DMU to become efficient, meaning its efficiency to become as large as possible and equal to the upper limit of 1 (or score 100%) (Xu et al., 2015). The slack variables correspond to price reduction, whereas projection values, which are the efficient targets, are estimated seeking to improve the performance of a service which does not lie into the efficient frontier.

Table 24 presents three (3) different DMUs (cloud computing provider bundles) of the compute-oriented group with five (5) categorical variables, using the DEA approach.

Variable	**CloudSolutions5**	**Google2**	**e24cloud.com2**
CPU (cores)	2	2	1
RAM (GB)	16	13	4
Storage (GB)	200	100	140

Price ($)	119	50	60
Auto-scaling	None	Horizontal	Vertical
$d^{AS(V)}$	0	1	1
$d^{AS(H)}$	0	1	0
$d^{AS(B)}$	0	0	0
$i^{AS(V)}$	0	50	60
$i^{AS(H)}$	0	50	0
$i^{AS(B)}$	0	0	0
Resource usage monitoring	NO	YES	YES
$d^{RU(Y)}$	0	1	1
$i^{RU(Y)}$	0	50	60
Web Interface	YES	YES	YES
$d^{WEB(Y)}$	1	1	1
$i^{WEB(Y)}$	119	50	60
Supported OS	Linux	Linux	Linux
$d^{OS(W)}$	1	1	1
$i^{OS(W)}$	119	50	60
Burstable CPU	Fixed	Fixed	Fixed
$d^{CPU(Y)}$	0	0	0
$i^{CPU(Y)}$	0	0	0

Table 24 A sample of dataset with some categorical variables using the DEA indicator approach.

The dummy variables that were created are labeled as $d^{a(b)}$ and the input indicators as $i^{a(b)}$. The dummies were multiplied with the input of the monthly price, resulting in the indicators. DMUs "CloudSolutions5" and "Google2" were found to be efficient with their score equal to 100%, whereas the efficiency score of DMU "e24cloud.com2" was estimated to be 75.83% having "CloudSolutions5" in its reference set with λ equal to 0.152174. Both "CloudSolutions5" and "Google2" lie into the efficient frontier but "Google2" needs to reduce its price 14.50$ (final bundle price: 45.50$), in order to be efficient as well.

The adoption of the DEA method aims to highlight the key role of non-functional features in relative efficiency. Furthermore, DEA focuses on the inefficient bundles and suggests the appropriate modifications, in order to move inefficient cloud bundles to efficient frontier, by reducing the price of each cloud instance. Initially, DEA is individually applied over the three categories (compute, storage, memory) that exclusively include functional attributes. Then, the dataset of the three categories has been enriched with non-functional attributes and their corresponding values and three DEA-oriented models have been developed.

6.5.1 Model Results based on functional results

The proposed model is initially applied over a dataset of cloud bundles that include only functional attributes. As already mentioned, compute power (vCPU), memory (GB), Storage (GB) and price ($) describe the cloud bundles. The only functional parameter, which participates as a categorical variable in the DEA model, is the supported operating system. Linux is chosen because it is free, thus the impact on the price of cloud instance is negligible.

As shown in Figure 19, the efficient DMUs, whose efficiency score is estimated to 100%, for the compute, memory and storage optimized groups are 3 out of 204 DMUs, 8 out of 103 DMUs and 5 out of 101 DMUs, respectively. Therefore, only 1.47% of compute cloud bundles are efficient, while 7.76% memory bundles and 4.95% storage bundles lie on the efficient frontier.

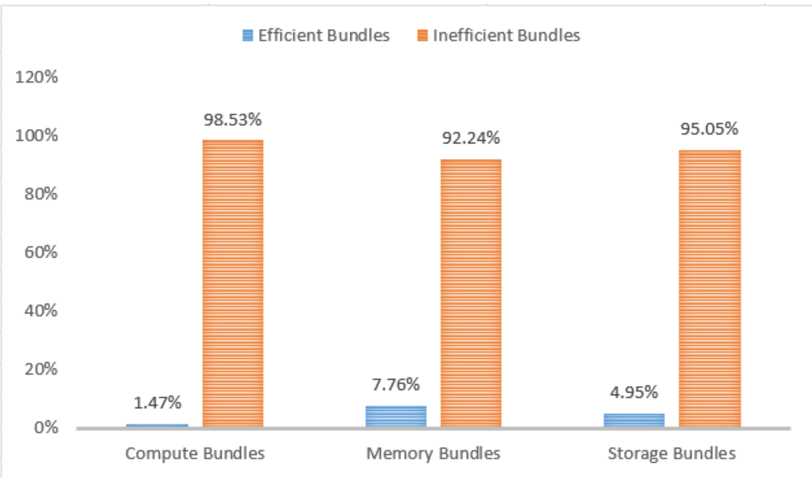

Figure 19

Overall evaluation of compute, memory and storage instances.

Table 25, Table 26 and Table 27 introduce the providers that demonstrate efficient bundles of each group.

Providers	Number of efficient cloud bundles
Google	1
DreamHost	1

Vps.Net	1

Table 25 Number of efficient compute instances per cloud provider.

Providers	Number of efficient cloud bundles
Microsoft Azure	1
CloudSigma	3
DreamHost	3
Storm	1

Table 26 Number of efficient memory instances per cloud providers

Providers	Number of efficient cloud bundles
Microsoft Azure	3
Google	1
DreamHost	1

Table 27 Number of efficient storage instances per cloud providers

Microsoft Azure, Amazon and Google are the cloud providers with the largest market share, however it is interesting to separately present their results. As shown in Table 28, 16.67% memory bundles and 33.33% storage bundles of Microsoft Azure lie on the efficient frontier, meaning they are estimated to have a score of efficiency of 100%, while there are no efficient compute cloud bundles. Furthermore, the efficient DMUs of Google for the compute and storage optimized groups are 8.33% and 12.5% respectively, whereas all of the memory optimized instances are considered to be inefficient. As far as Amazon is concerned, there are no efficient DMUs for any of the optimized instances.

	Number of efficient cloud bundles		
Providers	Compute Opt	Memory Opt	Storage Opt
Microsoft Azure	0	1	3
Google	1	0	1
Amazon	0	0	0

Table 28 Number of efficient bundles for the 3 most popular cloud providers per category of instances.

Figure 20 illustrates an overall ranking of the 23 providers all together. It is obvious that the most efficient provider is Microsoft Azure while Vps.Net presents the smallest number of efficient bundles.

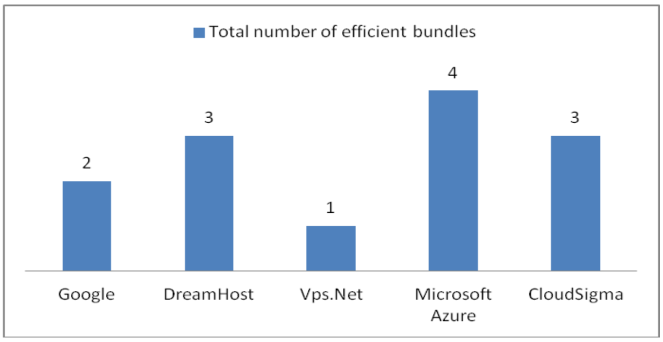

Figure 20 Efficient Providers

The proposed model also indicates the inefficient bundles and moves inefficient DMUs to the efficient frontier by reducing the input (price) and maintaining the outputs (CPU, Memory, Storage) at their current levels. The average price reduction was calculated, together with the standard deviation of the price. As calculated, compute optimized inefficient bundles need a 286.08$ price reduction on average, with a standard deviation s=408.95$. In the memory optimized group the average reduction of the price is 311.31$ and standard deviation is 497,47$. Finally, in the storage group, the average reduction of the price is 578.23$ and the standard deviation 753.20$. The values of standard deviations reveal the lack of homogeneity among bundles, since they are rather widely spread around mean values.

6.5.2 Model Results Including Non-functional Parameters

DEA-oriented model was also applied to an extended and enriched dataset that includes both functional and non-functional attributes. The addition of non-functional attributes in the dataset has increased the number of the collected bundles and their corresponding prices. The cloud bundles are described by functional attributes (vCPU, Memory, Storage) and by 14 non-functional attributes that are treated as categorical variables.

The efficient DMUs are 39 out of 401, 48 out of 204 and 35 out of 200 DMUs for the compute, memory and storage optimized instances, respectively. Thus, 9.72% of compute bundles and 23,5% of memory bundles are efficient. Finally, in the storage optimized group the rate of the efficient bundles is 17.5%. Figure 21 illustrates the rates of the efficient and inefficient DMUs.

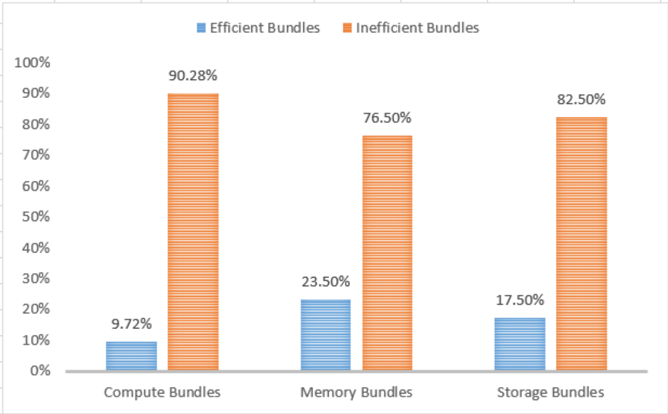

Figure 21 Overall evaluation of compute, memory and storage bundles

Despite that the collected cloud bundles were derived from 23 providers only a portion of them offer efficient bundles, thus Table 29, Table 30 and Table 31 present the providers that produce efficient bundles and their corresponding number.

Compute Optimized Group	
Providers	**Number of efficient cloud bundles**
Amazon	2
Atlantic.net	1
Cloudsigma	1
Cloudsolutions	4
Cloudware	4
Dreamhost	3
e24cloud.com	1
Exoscale	8
Gigenet	1
Google	1
M5	1
Microsoft Azure	2
Storm	3
VP.NET	1
Zippycloud	6

Table 29 Number of efficient compute instances per cloud provider.

Memory Optimized Group	
Providers	**Number of efficient cloud bundles**
Amazon	5
Atlantic.net	1
CloudSigma	5
CloudSolutions	2
Cloudware	3
Dreamhost	3
e24cloud.com	1
eApps	1
Exoscale	6
Gigenet	2
M5	3
Microsoft Azure	3
Storm	3
VPS.NET	2
Zippycloud	8

Table 30 Number of efficient memory instances per cloud provider.

Number of efficient storage instances per cloud provider	
Providers	**Number of efficient cloud bundles**
Amazon	3
Atlantic.net	1
Microsoft Azure	3
CloudSigma	4
Cloudsolutions	2
Cloudware	1
Dreamhost	2
e24cloud.com	3
eApps	1
Google	1
M5	2

Storm	4
VPS.NET	1
Zettagrid	1
Zippycloud	6

Table 31 Number of efficient storage instances per cloud provider.

Table 32 presents the number of the efficient bundles for the most popular providers of the cloud market, such as Microsoft Azure, Google and Amazon. Microsoft Azure provides 10% efficient compute bundles, 25% memory bundles and 16.66% storage bundles of Microsoft Azure lie on the efficient frontier. The efficient DMUs of Google for the compute and storage optimized groups are 5.26% and 6.25% respectively, whereas the memory optimized group of Google has no efficient memory. As far as Amazon is concerned, the efficient bundles for compute, memory and storage optimized instances are 8.33%, 35.71% and 16.66%, respectively.

	Number of efficient cloud bundles		
Providers	Compute Opt	Memory Opt	Storage Opt
Microsoft Azure	2	3	3
Google	1	0	1
Amazon	2	5	3

Table 32 Number of efficient bundles for the 3 most popular cloud providers per category of instances

Regarding the inefficient bundles, the average reduction of price, as well as the standard deviation were calculated. Therefore, in the compute optimized instances the average reduction of the price is 521.96$ and standard deviation is 2163$. In addition, in the memory group the average reduction of the price is estimated to be 461.9$ and standard deviation is 1019.5$. Finally, in the storage group the average reduction is 802.3$ and standard deviation equals 2098.3$.

6.5.3 Comparison

The proposed DEA-oriented model was applied over the three cloud bundles categories. An overall comparison between the DEA models for each category, highlighting the key role of non-functional is presented Figure 22, Figure 23 and Figure 24

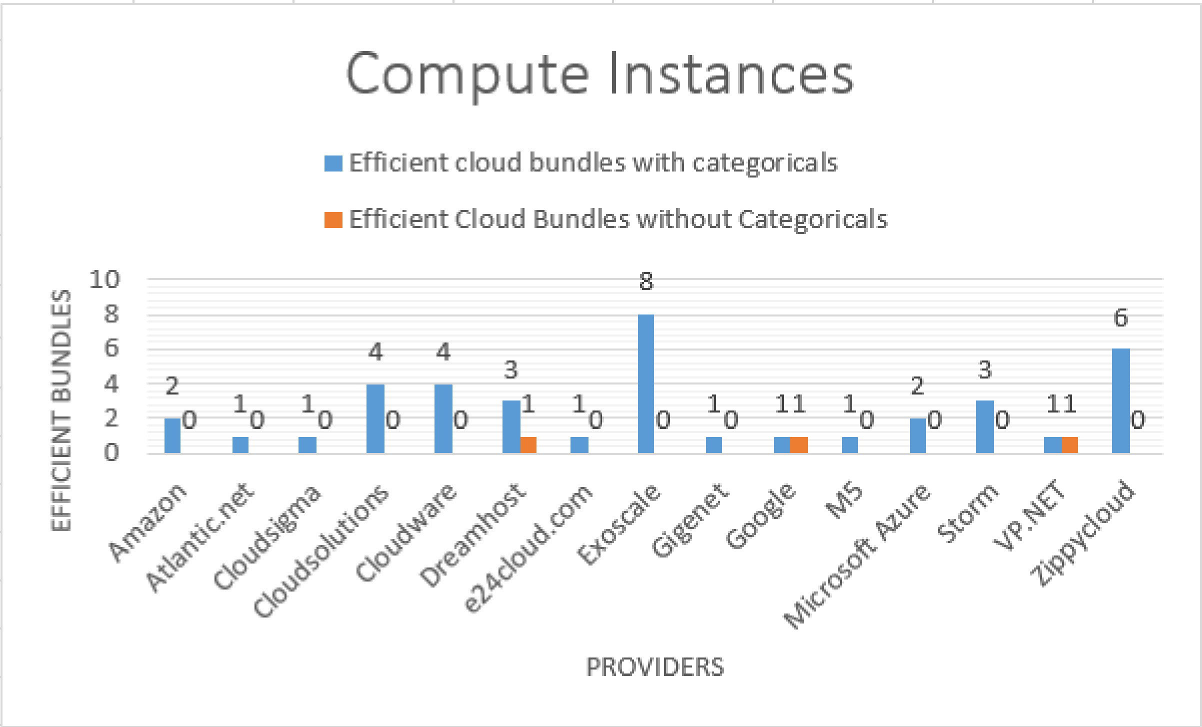

Figure 22 Comparison between compute instances with and without non-functional attributes

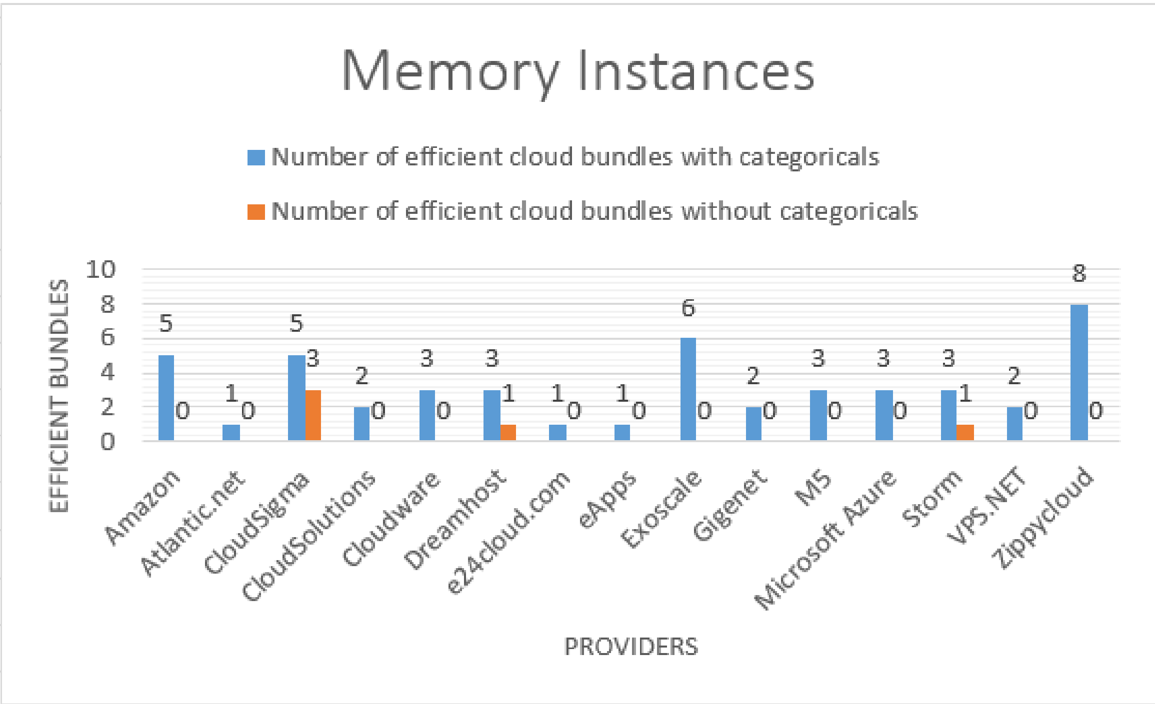

Figure 23 Comparison between memory instances with and without non-functional attributes.

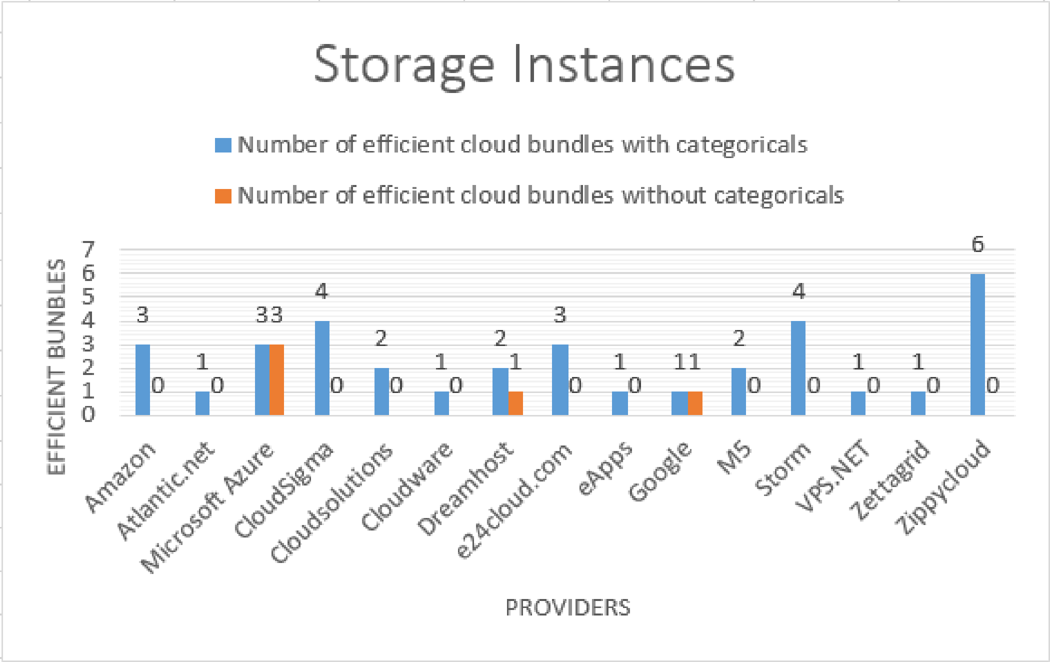

Figure 24 Comparison between storage instances with and without functional attributes

The proposed model is input-oriented, therefore the inefficient bundles become efficient through the proportional reduction of the price (Charnes et al., 1981). The following figures illustrate an overall proportionate movement of the price, for each group (compute, memory, storage), highlighting that the non-functional parameters affect the proportionate price reduction. For comparison reasons, a normal distribution plot with the same mean and deviation is imposed in each graph in order to give a better sense of the results. Proportionate movement describes the price reduction of the inefficient bundles in order to become efficient and frequency indicates the number of inefficient bundles.

Figure 25 and Figure 26, illustrate distribution of price reduction for the inefficient compute optimized bundles. Initially, Figure 25 indicates the distribution of price reduction for a DEA-oriented model based on the compute optimized dataset, excluding the non-functional attributes. In contrast, Figure 26 presents the distribution of price reduction for the compute optimized bundles, including the non-functional attributes. Non-functional attributes succeed in moving a larger number of inefficient bundles to efficient frontier with less price reduction. The horizontal axis shows the amount of price reduction needed for each bundle in order to become efficient, while the vertical axis (Frequency) corresponds to the number of bundles that needs the corresponding reduction.

Focusing on the DEA model which includes only functional attributes, it is derived that the majority of inefficient computed bundles, at a level of approximately 40%, can move to the efficient frontier with a maximum price reduction up to 100$. However, the participation of non-functional parameters in the model decreases price reduction, since the 41% of inefficient bundles become efficient with a price reduction up to 70$

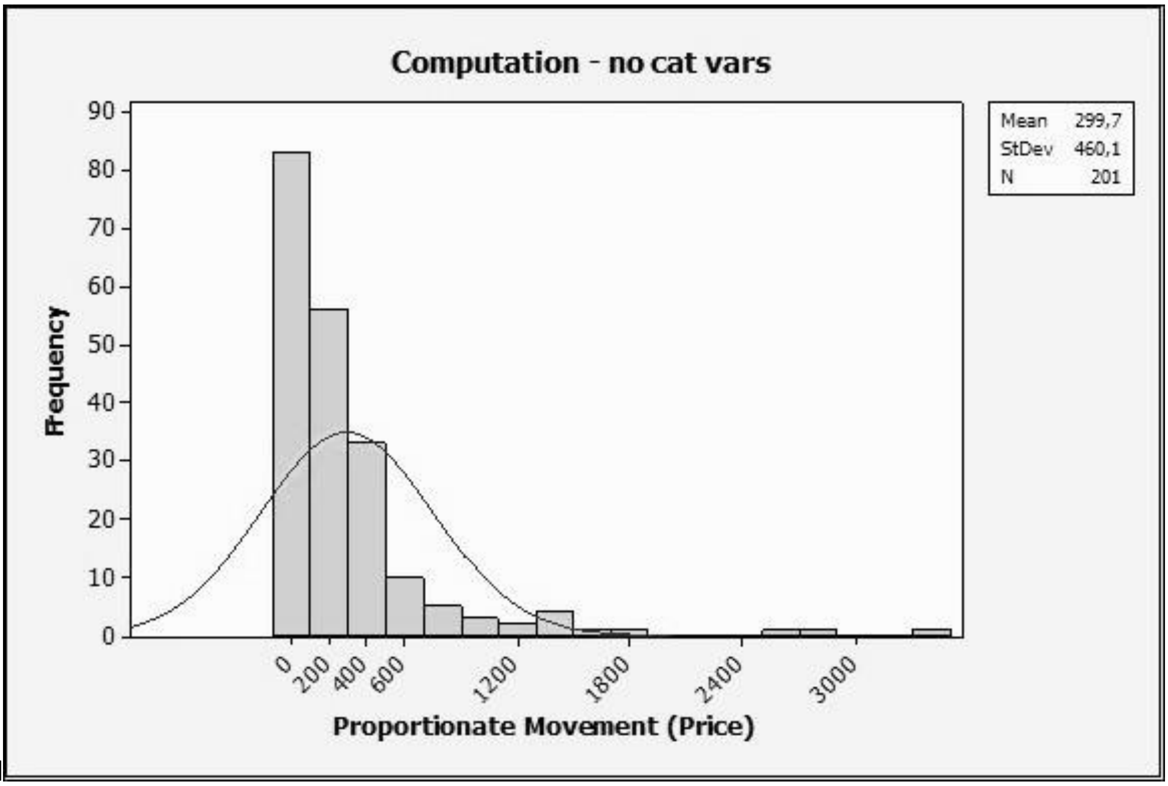

Figure 25 Distribution of price reduction for compute inefficient bundles without non-functional attributes.

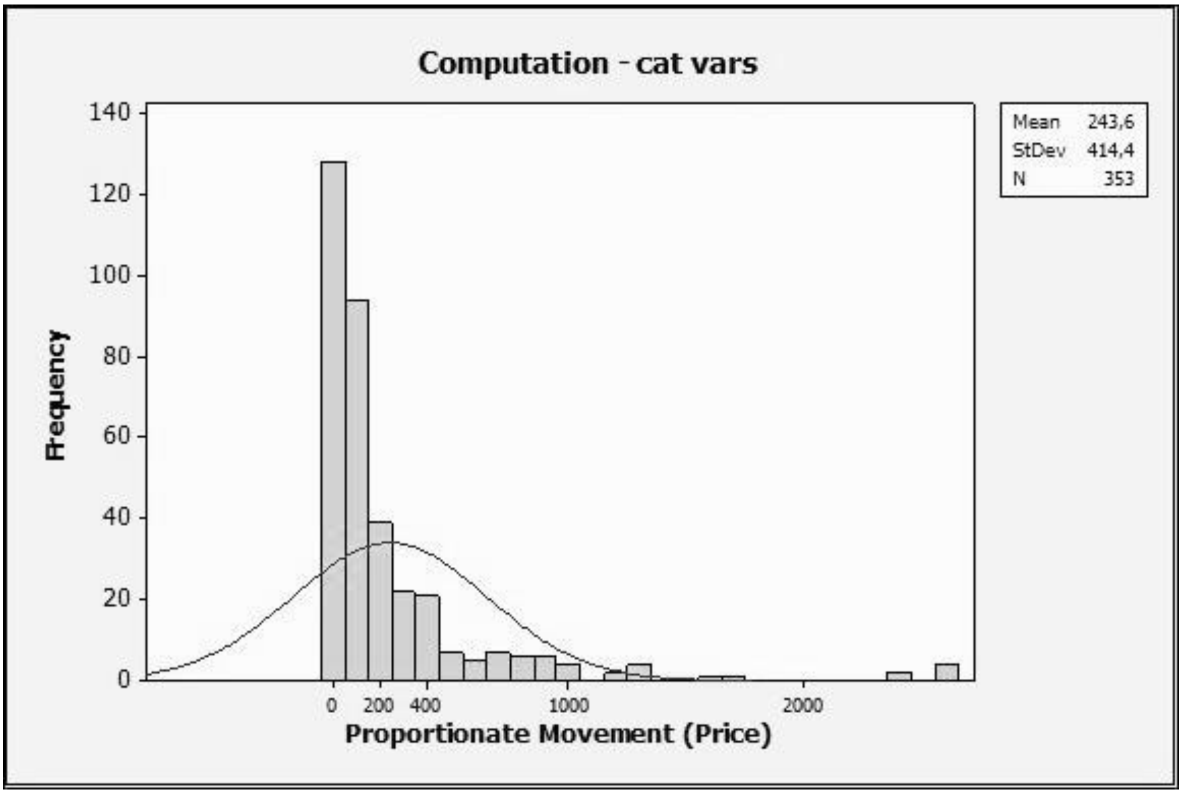

Figure 26 Distribution of price reduction for compute inefficient bundles including non-functional

Focusing on the memory group and the corresponding inefficient bundles, the results capture a similar trend with the compute group which is depicted in Figure 27 and Figure 28. The results show that the largest share of inefficient bundles (37%) without the non-functional parameters requires a price reduction of about 300$ in order to be efficient. Instead, 46% of cloud bundles that support non-functional factors require price reduction up to 150$.

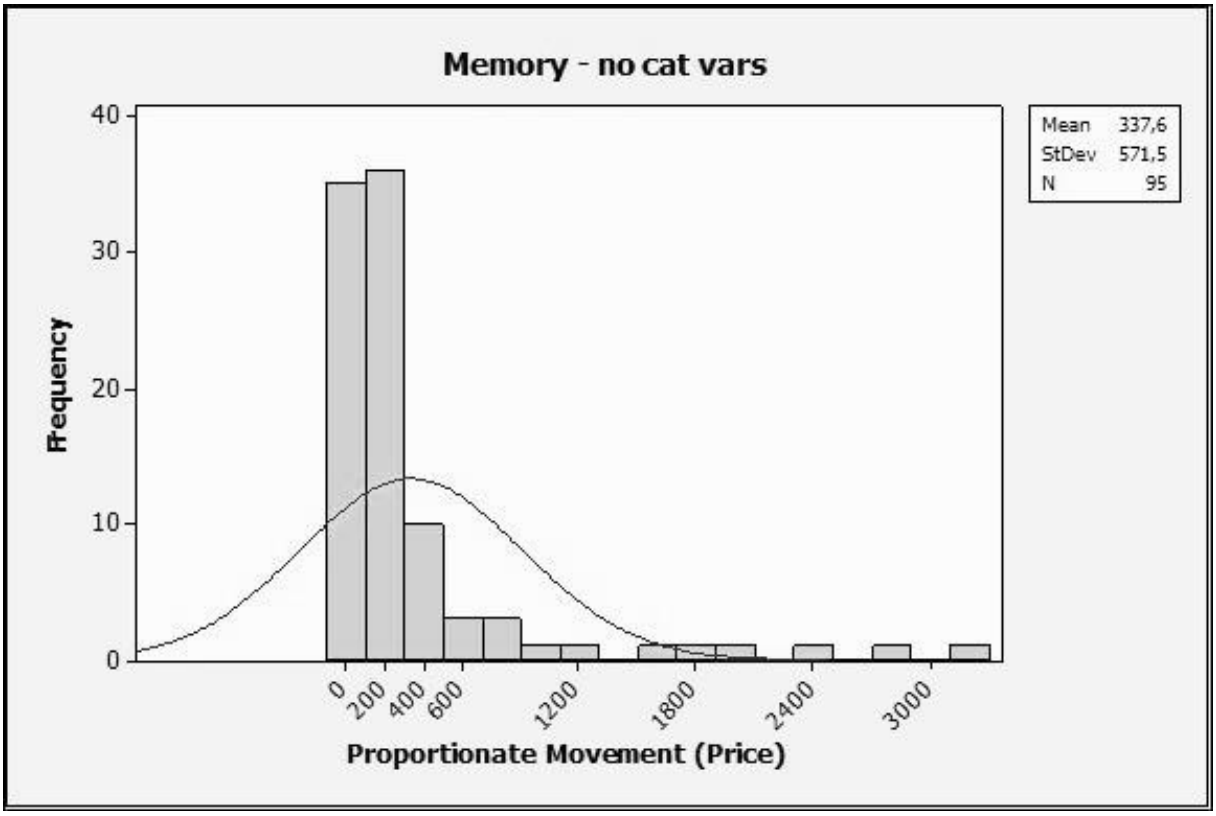

Figure 27 Distribution of memory inefficient bundles without non-functional attributes

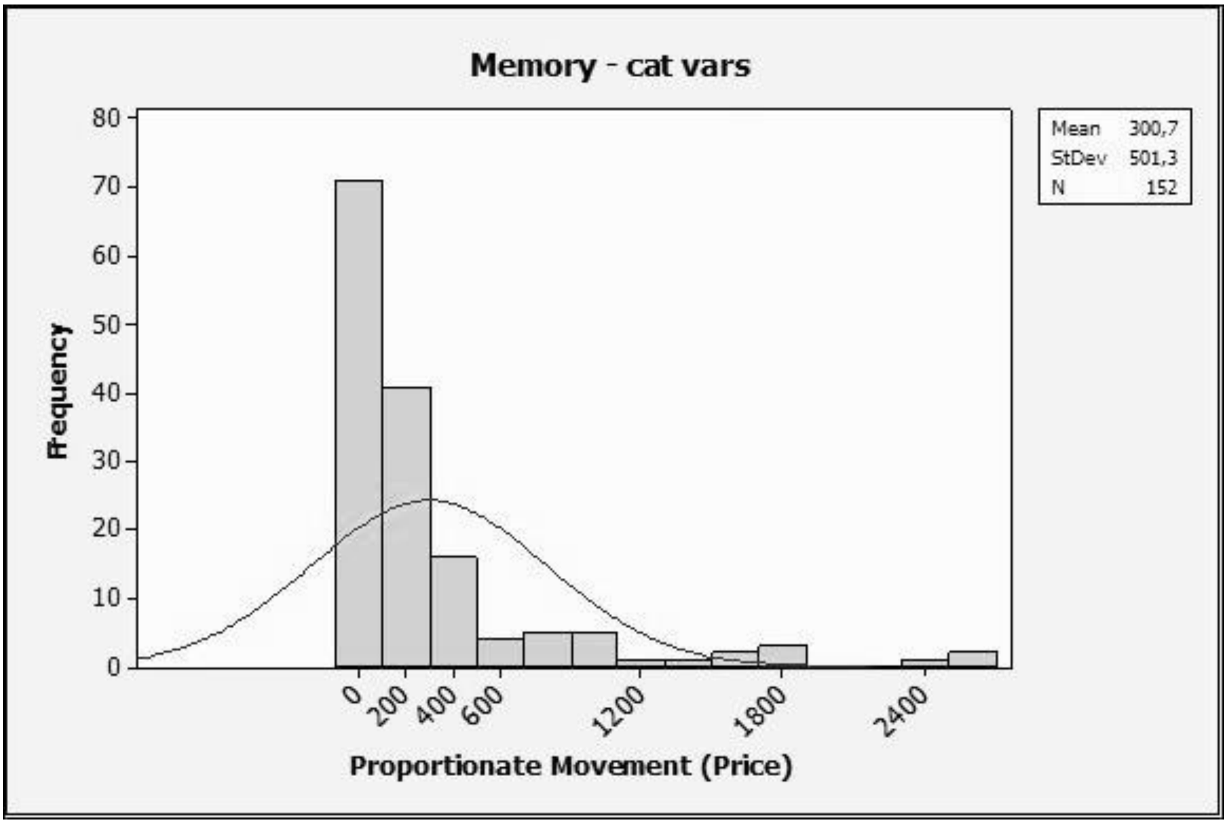

Figure 28 Distribution of price reduction for memory inefficient bundles including non-functional attributes

In the storage group and without considering non-functional parameters, the greater part of inefficient bundles, almost 32.5%, becomes efficient by reducing the mean price at about 250$, as shown in Figure 29. The incorporation of non-functional parameters is depicted in Figure 30, where 38.2% of inefficient bundles reach the efficient frontier by reducing price up to 100$.

All of the considered cases reveal the importance of the non-functional parameters to the shaping of efficient pricing schemes.

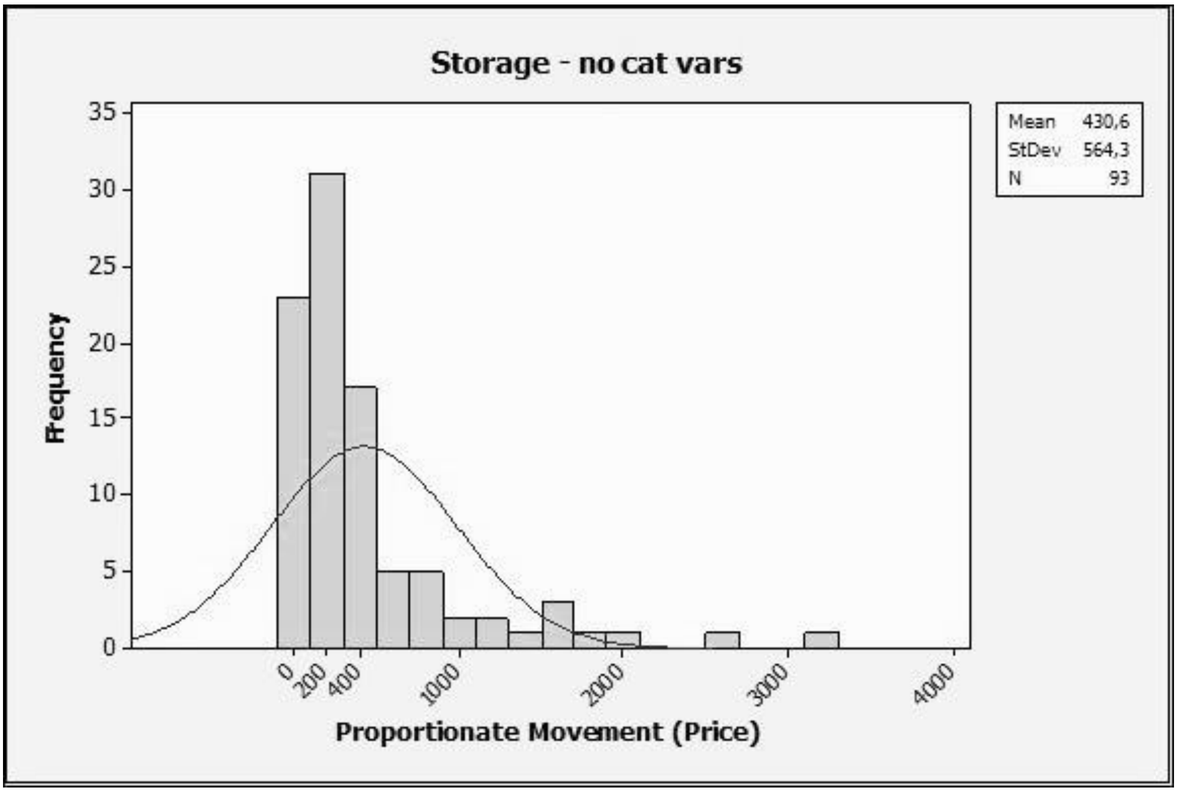

Figure 29 Distribution of price reduction for storage inefficient bundles without non functional attributes

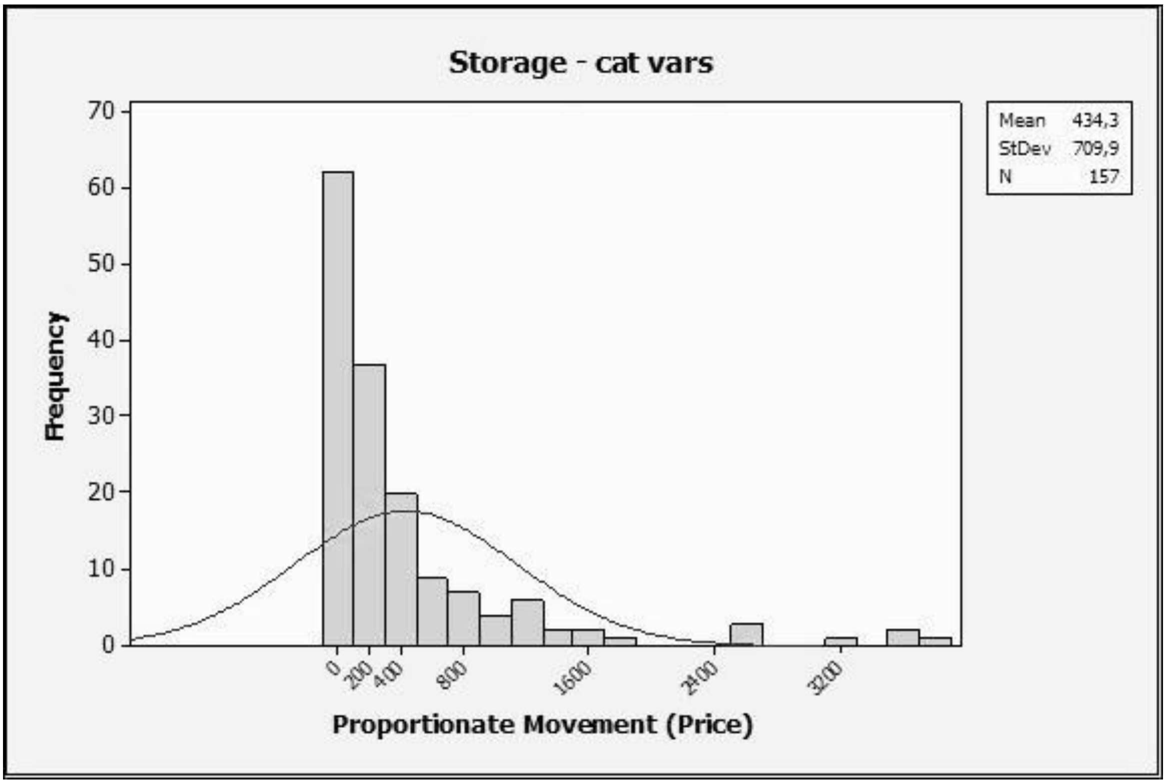

Figure 30 Distribution of price reduction for storage inefficient bundles including non-functional attributes

6.6 Conclusions

Cloud providers offer numerous and equivalent services and users can choose the service that fulfills their requirements, with price being the most influential factor driving their choice. However, this critical choice, based only on price is not always safe, because choosing the cheapest or the most expensive cloud service, it is not always the optimal service. The optimal solution is a cost-effective cloud service, which brings the greatest possible advantages or profits when the amount spent is considered. The cost-effectiveness is an important factor for users and providers to consider, because efficient cloud services may mean that less infrastructure is needed to run an application, thereby saving cost.

Towards this direction, Data Envelopment Analysis was adopted to estimate the relative efficiency of the selected and efficient bundles was pointed out. Popular providers, such as Amazon, categorize cloud instances into groups, fitting different use cases. Adopting the specific categorization of the bundles the collected cloud bundles have been categorized into three groups, compute optimized, memory optimized and storage optimized bundles and DEA was applied in each individual group. Initially cloud bundles were exclusively described by functional attributes and then non-functional attributes were added, highlighting the essential impact of quality on efficiency.

A DEA input-oriented model, based exclusively on price and functional attributes, was developed, which estimates the relative efficiency. Price is the input of the proposed model and functional attributes (cpu, memory, storage) are the outputs, whereas the collected cloud instances were derived from Cloudorado. The outcome of the DEA model points out that the number of efficient bundle is insignificant and the majority of cloud bundles are inefficient. Even popular providers, such as Google and Amazon, hold a small number of efficient bundles.

Aiming to examine the impact of quality on efficiency and analyze a possible relationship with price, non-functional attributes have been added, therefore the initial design of the DEA-oriented model was modified. Price and non-functional attributes constitute the inputs of the model, whereas functional attributes remain the outputs. In addition the collected dataset was enriched by adding non-functional attributes. The outcome of proposed model has highlighted a high impact of non-functional attributes on the efficiency of cloud services, since the rate of efficient bundles has been significantly increased.

The proposed methodology consists of a dual DEA model, which was applied to the whole dataset of collected cloud bundles and finally estimates their relative efficiency. It highlights the importance of non-functional attributes of cloud computing services to the performance and points out that high prices do not necessary signal high quality. According to the results, cloud providers that offer IaaS bundles including exclusively functional parameters present a smaller rate of efficient bundles, as compared to providers that enrich their bundles with non-functional attributes. Thus, non-functional parameters boost efficiency of cloud bundles and make vendors more competitive and profitable.

Furthermore, the DEA methodology is used to provide decision makers with a valuable techno-economic analysis tool that focuses on different competing cloud computing services available in the market. The proposed model examines inefficient bundles as well and can direct cloud providers of how to be efficient and competitive. It estimates the price reduction that is necessary in order to move inefficient bundles to efficient frontier. Inefficient bundles that include non-functional attributes require a smaller price reduction than IaaS bundles that are based only on functional parameters (CPU, Storage, Memory).

Chapter 7 End Users' Requirements for Pricing Policies of IaaS services

7.1 Outline

The current thesis proposes and develops pricing models that examine the multidimensional factor of price by adopting Hedonic methods, Data Envelopment Analysis and Structural Equation Model. All the aforementioned models represents providers' perspective, revealing the requirements (functional, nonfunctional) and the corresponding attributes that determine cloud price and affect efficiency. However price is strongly related with users' priorities and requirements, since users mainly select services that fulfill their requirements, while at the same time seek to obtain the best possible effective service at the lower possible cost. The current chapter adopts the PairWise Comparison framework in order to examine users' aspect and grades the importance of the attributes to the overall pricing of cloud services.

7.2 PairWise Comparison Background

PairWise Comparison (PWC) framework is an important Decision Making Tool that describes values and compares them to each other. It is an integral part of many decision making frameworks that enable the ranking of attributes, by allowing the end-users to compare them in pairs, instead of directly assigning their priorities (Saaty, 1977). This reduces the influence of subjective point of views, associated with eliciting weights directly. It is quite complicated to choose the optimal various options, especially when they are different. All the potential options are compared visually, leading to an overview that suggests the correct decision. PWC can been used as a stand-alone method or as part of a more complicated multi attribute decision making frameworks, such as Analytic Hierarch Process (Saaty, 1990)

Based on PWC users' perspective was examined by grading the importance of a set of cloud attributes estimating a weight for each one of them. Different and various criteria were used for the evaluation of the options, within the decision making processes. Multi-criteria decision analysis (MCDA) has successfully used Pairwise comparisons in numerous practical decision – making problems, either as a standalone method or as an essential ingredient of MCDA process, such as AHP (Saaty, 2003), the Weighted Product Method (WPM) (Brans et al., 1986), the Preference ranking organization method for enrichment evaluation (PROMETHEE) [64] and the Analytic Network Process (ANP) (Brans et al., 1986).

PWC effectively ranks the attributes, through a structures process, highlighting their impact on a general goal (Triantaphyllou, 2000, Yager, 2004). The PWC framework ranks the attributes by allowing a number of end-users, say M, to compare the various attributes Ai (1≤i≤N) in pairs, instead of assigning their priorities in a single step (Saaty and Vargas, 2001). This reduces the influence of subjective point of views, associated with eliciting weights directly. Each end-user compares all potential combinations of A_i and A_j. The result of these judgments for the mth end-user are stored in a square N×N reciprocal matrix P(m)=[P_{ij}(m)], which will henceforth be referred to as a pairwise comparison matrix. The value of the element P_{ij}(m) reflects the importance of attribute A_i over A_j. The end-user needs to complete only the upper triangular elements (i<j) of P(m) since by definition we have P_{ij}(m)=1/P_{ji}(m) and P_{ii}(m)=1 for a reciprocal matrix. The weights w_i(m) of attribute A_i according to end-user m can be calculated with various ways. The most widely adopted approach is to solve the eigenvalue problem P(m)xq(m)=λqxq(m), where λ_q are the eigenvalues of P(m) and x q(m)=[xpq(m)] are the corresponding eigenvectors. Assuming that the eigenvalues are ordered so that λ1 is the largest eigenvalue, then the weight of attribute Ai is estimated by normalizing the elements of the principal eigenvector x_1(m) as follows (Saaty, 2003)

$$w_i^{(m)} = x_{1i}^{(m)} \left[\sum_{l=1}^{N} x_{1l}^{(m)} \right]^{-1} \qquad (30)$$

In order to further simplify the comparisons, introduced the nine-level scale shown in

$P_{ij}^{(m)}$	Explanations
1	A_i and A_j are equally important
3	A_i is slightly more important than A_j
5	A_i is strongly more important than A_j
7	A_i is very strongly more important than A_j

9	A_i is absolutely more important than A_j
2,4,6,8	intermediate values
Reciprocals of above	used in analogous manner when A_j is more important than A_i

Table 33 The nine-level fundamental comparison scale

One way of measuring the inconsistency of a pairwise comparison matrix is to calculate the Consistency Ratio (C.R.) defined as C.R.=C.I./R.I., where C.I. = (λ_1-N)/(N-1) is the Consistency Index and R.I. is an average random consistency index derived from a sample of randomly generated reciprocal matrices with elements scaled according to (Saaty, 2003). If C.R. is smaller or equal than 0.1 is considered acceptable and in this case, the matrix is said to be nearly consistent (Saaty, 2003).

After all the comparisons have been completed, the average weight w_k for each attribute A_k is calculated by averaging out the weights $w_k^{(m)}$ obtained by the M end-users.

$$w_k = \frac{1}{M}\sum_{m=1}^{M} w_k^{(m)} \tag{31}$$

The weights w_k define the priorities of the attributes and hence the outcome of the PWC process.

Applying PWC on the proposed model of Figure 16, functional and non-functional requirements of cloud services are rated. The estimated weights, denoted by w_k and f_{jk}, represent the contribution of each attribute and category to cloud pricing, capturing end-user perspective. Towards this direction, each end-user m performs a series of PWCs according to the aforementioned procedure and the weights are finally estimated.

A number of M=20 end-users with technical skills, working at Harokopio University, have filled out the PWCs matrices. This group size is considered to be adequate for such decision making problems, since it was shown in previous literature (Triantaphyllou, 2000) that there is no much difference in using more than M=15 participants. This is because the rate of decrease of an important measure named the probability of rank reversal of the final ranking is already small for M>15. The pairwise comparisons were conducted by a web-based survey platform incorporating all elements of the PWC framework. The web platform was developed was based on PHP programming language and maintained by the Harokopio University of Athens. The data supplied by the users are saved in a database and the survey designer can perform the pairwise comparison in order to estimate the weights that signify the importance of categories and attributes according to the PWC framework.

7.2. 1 Relative Literature

PWC can be used in a wide range of areas, including industry, healthcare, education government, energy planning, and communications (Huang et al., 2008, Lee and Kozar, 2006, Chan et al., 2006, Liberatore and Nydick, 2008, Gerdsri and Kocaoglu, 2007, Dede et al., 2011b, Dede et al., 2011a, Dede et al., 2015, Abildtrup et al., 2006). Cloud computing is a research field that has already adopted PWC, to analyze crucial aspects, such as the prioritization of alternative cloud services (Garg et al., 2013, Sun et al., 2014, ur Rehman et al., 2011, Sun et al., 2013, Martens and Teuteberg, 2012, Lee and Seo, 2016). Furthermore, PWC has been adopted for the estimation of weights that point out the cloud-path selection (Wu et al., 2012). In addition, Nayak (Nayak and Tripathy, 2016) used PWC in AHP as a decision maker in the backfilling algorithm, in order to choose the possible best lease from the given best effort queue and schedule the deadline sensitive lease in cloud computing. Furthermore, PWC is used by Andrikopoulos (Andrikopoulos et al., 2013), proposing a migration decision support system that incorporates both offering matching and cost calculation, combining features from various approaches in cloud state-of-the-art. As far as cloud pricing policies are concerned, Kar (Kar and Rakshit, 2015) has adopted PWC and proposed a pricing approach for IaaS based on its perceived value to multiple key stakeholders, while Andrikopolos (Andrikopoulos et al., 2013) proposed a value-based pricing approach for IaaS based on fuzzy PWC sets.

7.3 Results of PWC

The PWC methods examine the importance of the attributes that affect the price of cloud services from the end-user perspective, in terms of both categories and attributes. Figure 31, - Figure 36 illustrate the weights of the categories and attributes.

The output of PWC model indicates that the performance category is the most important, as its weight reaches 32.51%. It is quite justifiable since users are willing to pay for cloud services if they do satisfy their performance needs. In addition, availability follows, rated with a high priority of 25.51%, pointing out that cloud users are highly interested in cloud services that can be available from anywhere and anytime access to services. Furthermore, the security has also an essential impact, accumulating 20.38% of the overall importance, capturing the great public concern about the crucial privacy aspects related to cloud services.

Usability and elasticity seem to have the lower priority, depicting the current situation of cloud services where usability features such as APIs, images from cloud server, one account etc, are already offered by the majority of cloud providers. The minor impact of elasticity highlights that users are willing to pay for all the aforementioned features of cloud services, rather than high elasticity attributes that may increase the price of their preferable cloud services. Figure 31 presents the impact of categories on price.

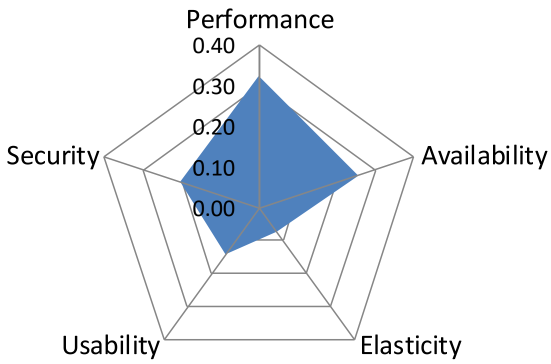

Figure 31 Impact of categories on price

The impact of cloud attributes on each category was examined. Figure 32 depicts performance aspects and it is obvious that end users are concerned about the CPU and memory rather than the storage capacity. In fact, the amount of processing power that a hypervisor provides to a virtual server is a significant factor that affects price of the related cloud services. RAM is also a essential feature for which end users want to pay, given that RAM of high capacity is related to speed and fast execution of cloud applications.

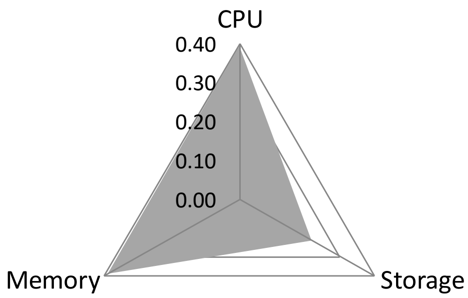

Figure 32 Weights of Performance

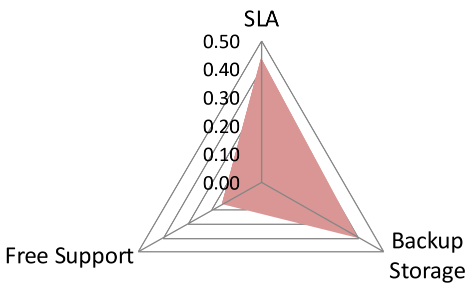

Figure 33 Weights of availability

Focusing on availability, Figure 33 reveals that SLA and backup storage seem to be the dominant attributes accumulating weights of 44.0% and 39.96%, respectively. SLA guarantees that cloud services can only be offline for the agreed time period and it seems that end users really demand this level of service and are willing to pay the extra costs associated with this. In addition, end users rank backup storage at a high level, pointing out the need for sufficient backup storage which enables the maintenance, management, retrieval and restoration of backup data for any individual, application, computer, server or any computing device. Free support is a feature of low priority, revealing that end users are not interested in extra charges for additional support.

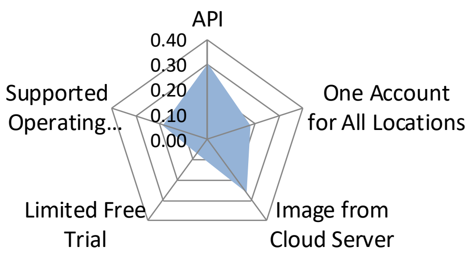

Figure 34 Weights of usability

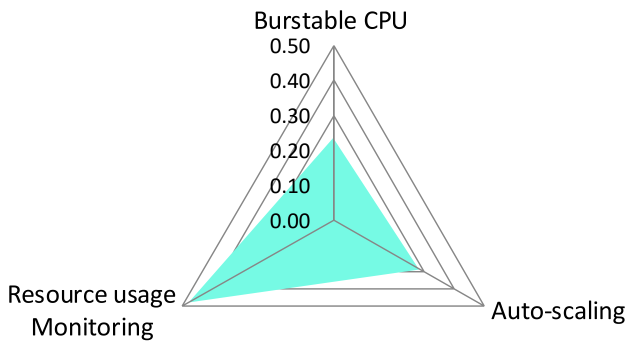

Figure 35 Weights of elasticity

In terms of usability features and according to Figure 34, API and image from cloud server seem to be the most important attributes, accumulating importance weights of 30.06% and 26.36%, respectively. API management capabilities guarantee autonomic capability and interactions of cloud servers, therefore their vital role has been justifiable. The impact of cloud server image on usability points out the end users' needs for storing configuration and static data in other VMs without complexity. The rest of usability aspects seem to be of minor importance reflecting that all of them more or less are offered by the majority of the bundles of the different cloud providers.

Resource usage monitoring is the dominant attribute of elasticity category with an estimated weight of 47.85%, as shown in Figure 35 Monitoring of infrastructural resources in clouds holds an essential role for pricing policy, since it implies application guarantees like performance, availability, and security. Auto-scaling and burstable CPU are not negligible, with estimated weights of 23.61% and 28.54%.

Examining the category of security, based on Figure 36, encrypted storage seems to take the precedence over general data protection regulation, highlighting that people are willing to pay for an efficient storage encryption to ensure the protection of their data. The main advantage of storage encryption is the fact that hardens the core of the network. Multiple ciphers can be used for individual files, folders, or data volumes. In addition, alternative encryption arrangements can be used, for data in transit and for stored and archived data. Cloud services vendors should implement effective security-related methods.

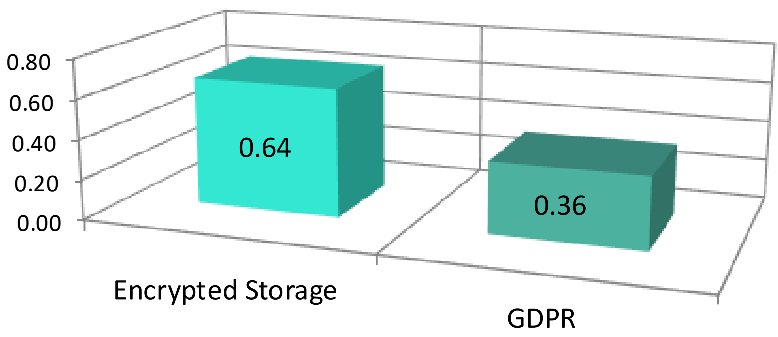

Figure 36 Weights of Attributes of Security

7.4 Conclusions

An approach for capturing the relationship between cloud attributes and price was developed and presented, revealing the attributes and the requirements that end users consider important in the determination of the final cloud price. As mentioned above, IaaS services are described by functional and non-functional attributes. Non-functional attributes are classified into four categories (security, availability, elasticity, usability) and functional attributes (cpu, memory, storage) define the performance category.

Despite that performance is the leading adjuster of price for users, the contribution of non-functional categories is not negligible, since PWC points out the essential role of non-functional categories on price. Availability and security highly contribute to the shaping of cloud pricing, followed by usability and elasticity, with a minor impact on price. In addition the PWC calculates the weights of each cloud attribute that define the corresponding category. Therefore, end users are willing to spend money on encrypted storage rather than GDPR policy. In addition, resource usage monitoring is the dominant attribute of elasticity category with an estimated weight of 47.85% and API seems to be the most important of usability with an estimated weight of 30.06%. Service Level Agreement (SLA) appears to be the most essential attributes of availability, whereas cpu holds the role of the leading attribute of the performance category.

Chapter 8 Conclusions and future work

8.1 Conclusions

In a data-driven society, a rapidly increasing number of businesses adopt cloud technology to enable their digital transformation. Despite the fact that cloud computing has entered its second decade, it still continues to grow vigorously and businesses embrace IaaS, PaaS and SaaS models, seeking to support their business operation. Cloud computing growth continues to accelerate as executives across all industries and businesses benefit from its advantages, such as flexibility, easy deployment, scalability and cost savings. Businesses can expand their IT infrastructure without upfront capital investment and adopt cost effective cloud solutions, thus cloud computing is becoming a great financial saver for businesses seeking higher computational speeds and efficiency for less money and energy.

The cost benefits that cloud computing offers to its users is something that has been considered as expected. However, what impact is this causing to the cloud provider companies? Cloud providers are in a bind over the pace of their infrastructure revamp. They have large upfront cost associated with building data centers and investing in sales and marketing to acquire users and hold onto them.

The IaaS model is the most straightforward model of the cloud and its continual growth has increased the number of providers that offer infrastructure services. Popular vendors such as Microsoft, Amazon and IBM offer IaaS solutions and have significantly increased their revenues by expanding the profitable and safe confines of their traditional business operation. The imperative demand for qualitative and financially optimal cloud services has driven a fierce competition among cloud providers that aim to increase their grip on the market and maximize their revenues. Providers offer solutions that fulfill users requirements combined with affordable prices, since price is the determinant factor that drives users to cloud adoption

Since cloud computing has met exponential growth, the cloud providers have rapidly innovated their IaaS services with new configurations and new pricing policies. The pricing policies for IaaS services are complicated, which makes purchasing decision for users difficult. There is an essential differentiation among the providers, when it comes to pricing process plus there are no standards for the pricing policy. Therefore, it is difficult for users to understand each pricing policy, compare and evaluate the price of an IaaS solution among a number of different offerings

Therefore, the current thesis examined pricing policies and developed pricing models, taking into consideration fundamental cloud attributes and requirements that describe the functionality and the quality of the cloud.

The increasing use of IaaS services has upgraded their functionality but has also posed Quality of Service (QoS) as a challenging issue. Cloud quality is described by the non-functional attributes and the requirements that present constraints and set cloud's operation. Users demand these qualitative attributes and providers are willing to fulfill their demands with additional charge. Therefore, the functionality and the quality of cloud computing were integrated into the pricing analysis, through their corresponding attributes that represent the specific operations. Cloud functionality was described by the fundamental attributes of the cloud infrastructure, such as compute power and storage, whereas the quality of cloud was defined by non-functional attribute, such as encrypted storage and autoscaling. Presenting accurate and generalized conclusions about the impact of the cloud attributes on quality, all the non-functional attributes were also categorized into four (4) non-functional requirements (elasticity, availability, security, availability), based on their operation.

The pricing of a cloud service is a major concern for both users and providers and determines the relationship between them. Therefore, a twofold approach was examined, that introduced and analyzed both providers' and users' aspects about the pricing process. Furthermore, the pricing models pointed out cost effective IaaS solutions that benefit users, but also examined how each cloud provider invoiced their IaaS services and analyzed the impact of the cloud functionality and quality on the price determination and cloud efficiency. The pricing models were developed and evaluated, confirming that price is a multidimensional factor of cloud environment.

The proposed pricing models were based on popular techniques, which are referred in various research fields.

Concerning providers' aspect the following schemes were adopted:

- Hedonic Price Index
- Data Envelopment Analysis (DEA)
- Structural Equation Model, (SEM)

In addition, decision making method PairWise Comparison (PWC) framework was applied regards to users' aspect.

The above methods were applied, using data collected from Cloudorado platform. Through the implementation of each method, the collected dataset was updated and extended, depending on the specifications of each method. For example a hedonic price index was initially constructed based on the functional attributes and the collected data were derived from 27 providers. Then the price index was extended, including cloud bundles described by the functional and the non-functional attributes. Thus, the dataset was increased and the number of the collected cloud instances was changed. Even though the data that were used for the implementation of each method were different, the results of each method presented a trend that led to precise and accurate conclusions.

Hedonic Methods and Structural Equation Model were adopted to analyze and examine the impact of cloud attributes and requirements on price, capturing providers' aspect. In addition, Data Envelopment Analysis was applied, pointing out the cost effective cloud instances, highlighting the essential role of quality in the determination of efficient cloud solution Pair Wise Comparison framework was used to indicate users' aspect, by grading the importance of the cloud attributes to the overall pricing of cloud services, conducting a structured web survey.

Based on the results of each method, it is unquestionable that the quality holds an essential role in the shaping of the final price. Even though, the dataset was enriched and modified and each method introduced different criteria for the development of the pricing model, the final results agreed that the role of quality in the determination of the price is not negligible.

According to provider's aspect, the outcome of the price index revealed that the non-functional attributes highly influenced pricing policy. However there were no accurate conclusions about the impact of non-functional requirements on price. For example, the security requirement was defined by the Safe harbor/ EU Directive/95/46/EC was a significant regulator of the price but it was blurry if the security requirement was the dominant factor that influenced price, since encrypted storage had rather lower importance. Therefore, the Structural Equation Model was adopted, in order to examine the extent at which non-functional (security, availability, usability, elasticity) and functional (performance) requirements contributed to the cloud price.

As mentioned above, the price determines the relation between providers and users, therefore PWC framework, that points out the users' aspect, was adopted for capturing the relations among the price and the functional (performance) and the non-functional requirements (security, availability, elasticity, usability). An interesting comparison of the two aspect follows.

8.2 Comparative Analysis providers- users aspect on pricing

Comparing the results of SEM and PWC techniques, it seems that performance is the dominant requirement that mainly influence price for both approaches. On the one hand, providers offer a variety of bundles, primarily based on different values of performance attributes such as memory, CPU and storage following an incremental pricing strategy and the end user ends up paying more as performance specifications are improved. This is consistent with the user aspect and behavior as potential consumers of cloud services. With more than one decade in the cloud era, users are accustomed to expressing performance requirements in terms of number of cores/threads, memory and storage. Examining the results for the performance attributes reveals that RAM and CPU seem to have the greatest impact for both perspectives. This fact is an evidence that pricing schemes take into account user needs on performance characteristics, since they determine the shaping of price into different pricing bundles.

Availability is also highly rated for both perspectives. Cloud providers appear to agree with the users in the context of availability attributes, where SLA is a major concern for both. Focusing on elasticity features, it appears that resource usage monitoring is an essential attribute from both aspects. The cloud users are interested in achieving the appropriate SLA demands, whereas the main interest of cloud providers is to assess if the required demand can be served to end users. Providers aim at offering high availability services, mostly related to SLA at extra charge, since the users are willing to pay more for a reliable cloud service. Towards this end, a monitoring framework is necessary, since cloud hosts are subject to varying load conditions. Considering the Quality of Service (QoS) requirement as an example of performance, the inappropriate provisioning of resources may lead to unexpected performance bottlenecks. ,. Along with the availability of the network infrastructure, cloud availability is a key factor there as well, since data will need to be processed and monitored in real time

Security is also significantly contribute to the shaping of price for both perspectives. Given the nature of existing cloud applications which are already supporting a variety of e-health and e-government systems, it is not surprising that both end-users and cloud provider place attention in security aspects of their solutions. Users think that encrypted storage is of paramount importance, whereas, providers give a precedence to GDPR. GDPR comes second for cloud users, which is possibly a reflection that the users believe that cloud vendors are obliged to be compliant with GDPR principles on the protection of personal data. Cloud vendors should take into account at their pricing strategies the crucial aspect of storage encryption. Encrypted storage protects users from data leakage, and in case of any unauthorized modification of data by the providers, users are informed. In addition the activation of this specific feature ensures them that their data are safely backed up and can be accessed from anytime and anywhere. Users can share their data only with their own authorization with the parties they trust. Two criteria are considered to help determining the potential effectiveness of any storage security plan. On the one hand, the cost of implementing the plan should be a small fraction of the value of the protected data. On the other hand, it should cost a potential hacker more, in terms of money and/or time, to compromise the system than the protected data. In this context, storage encryption is often seen as an ideal solution for cloud services. This disagreement in security aspects, must urge providers to modify their pricing policy and essentially upgrade services relative to encrypted storage by adopting the highest –grade encryption methods and also ensuring that only users control the encryption key. Again, the high importance rate of security reveals the great public concern on privacy aspects and providers seem to be in compliance with this crucial need.

Usability has a minor impact on price for both points of views, since most of the services are already offered by the majority of the cloud providers and users seem to be in accordance with this. Considering usability requirements, both points of view have similar opinion, since image from cloud server and API has a significant impact on this category for price shaping. From the viewpoint of providers, limited free trial follows, whereas one account for all location and the operation system attributes present slight impact on usability requirement. Considering the viewpoint of users, there is a disagreement about the operating system, which is quite neglected by the vendors. Cloud providers offer numerous versions of operating systems applying different pricing plans. Examining Amazon's market place for the operating system , it arises that the majority of operating systems are offered with additional charge, based on the leasing period, such as hourly, monthly and annual usage of the software license. This disagreement about operating system captures users' request for freeware licenses but without quality of service degradation.

Interestingly enough there is considerable inconsistency between vendors and consumers regarding elasticity. Due to the technical implications involved in terms of managing a cloud infrastructure with dynamic requirements for each node, elasticity is highly rated for providers but an aspect of minor significance for users. Pricing strategies of the vendors should really take into account the actual user needs. However, this disagreement does not negatively affect pricing policy of the providers, since optimal elasticity is beneficial for end users. Even if elasticity is a requirement of high importance for previous pricing schemes, the strategies should be updated taking into consideration the evolution and differentiation of user needs. From users' viewpoint elasticity is managed through cloud interfaces, where end users declare their requests, such as activation of auto-scaling feature. On the other hand, providers are responsible for offering, managing and upgrading cloud infrastructure aiming at fulfilling elasticity requirements. Cloud providers usually include automated monitoring services that manage resources of application. For example, Amazon (2018a) monitors cloud application automatically adjusts capacity to maintain predictable performance of the service. The different approaches about this specific elasticity justifies that elasticity holds a crucial role in the pricing policy of the provider.

The comparative results of the two applied methods (SEM, PWC) can be a useful tool for cloud providers since users' perspective is highlighted. Users present their requirements to the providers and they finally select the optimal cloud solution driven by the offered computational resources, the quality of service but mainly by the price. Therefore, cloud providers that aim to increase their market share and their profitability should analyze customers' aspect and modify their pricing policies taking into consideration the needs of end users. Figure 37**Error! Reference source not found.** illustrates a comparative presentation of requirements ranking, based on both aspects.

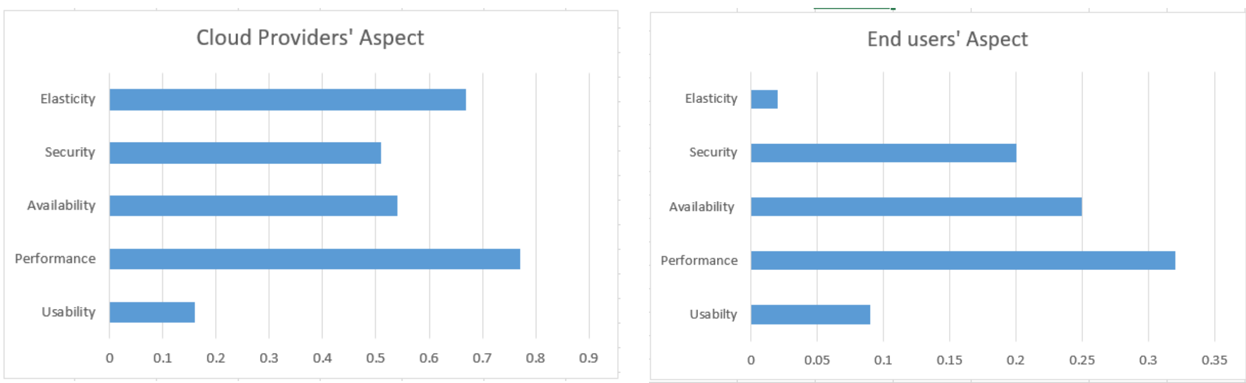

Figure 37 Comparative presentation of requirements ranking from both perspectives

8.3 Overview of the proposed pricing models

The pricing of IaaS services was examined through different approaches and methods and various different results were presented. However, the results of the aforementioned methods coincided that non-functional cloud attributes and requirements hold a leading and essential role on pricing for both providers and users. Usually non-functional requirements are not measured by number and mainly represent a positive and negative influence in the pricing policy. The proposed models accomplished to quantify the nonfunctional attributes and pointed out to which extent functional and non-functional attributes and requirements influenced the final price. Table 34 sums up the proposed pricing models.

Methods	**Description**	**Cloud Case**	**Results**	**Implementation**
Hedonic Pricing	Identifies price factors	A price index which	• Subscription holds a	(Mitropoulou et al., 2016,

	according to the premise that price is determined both by internal factors of the good being sold and external factors affecting it.	examines to which extent functional and non-functional attributes contribute to the shaping of the price.	determinant role in the shaping of price. • Non-functional attributes highly contribute to the determination of cloud price	Mitropoulou et al., 2017, Mitropoulou et al., 2015)
Structural Equation Model	Describes causal models and analyzes structural relationships between variables.	A pricing analysis is presented and points out the requirements that participate in the shaping of the cloud price.	• Performance is the most important requirement in price determination. • Non functional requirements highly contribute to the shaping of the final price.	
Data Envelopment Analysis (DEA)	Measures the relative performance of organizational units	An input-oriented pricing model is developed that calculates the relative efficiency of cloud bundles	• Cloud qualitative attributes boost efficiency. • Inefficient cloud services that include qualitative criteria need smaller price reduction to move to efficient frontier.	(Filiopoulou et al., 2018)

PairWise Comparison	Compares entities in pairs and judges which entity is preferred.	A PWC model is developed and examines the importance of the attributes that affect the price of cloud services	• Performance is the requirement that holds determinant role in the shaping of price • Availability and Security are highly essential	

Table 34 Proposed pricing models

8.4 Contribution

IaaS pricing and the factors that determine the shaping of price constitute the objective of the current thesis. In that context, it was vital to describe the architecture and the economic aspects of cloud computing. Therefore in Chapter 2 a brief introduction to the cloud is presented, by giving the definition and describing the offered services and deployments models of cloud computing. In addition to that, a detailed analysis about the pricing process is presented in Chapter 3. The economic aspects of cloud are presented by outlining the economic benefits of the cloud and its diffusion into the market. Moreover, capital and the operational expenditures of a business are introduced and analyzed, presenting at the same time a case study that highlighs the economic advantages of the adoption of IaaS services from a startup business.

Pricing models are examined and developed, based on popular methods and a two fold approach is presented that introduce and analyze both providers' and users' aspects. The pricing models are defined by the functional and non- functional attributes of IaaS model. Functional attributes always hold a leading role in the development of a pricing model and their importance was rather expected because the users are willing to pay for high computational power and large storage capacity. However, the qualitative cloud features that define how the cloud should operate, are usually negligible. In this context, the current thesis quantifies the non-functional attributes and offers them an equivalent role in the development and implementation of a pricing model. Chapter 4 and Chapter 5 introduced pricing methodologies, from the standpoint of the cloud provider, based on the Hedonic Model and the Structural Equation Model methods. Additionally, Chapter 7 examines the user perception of pricing, by adopting PairWise Comparison

Cloud efficiency is analyzed in Chapter 6, adopting Data Envelopment Analysis and focusing on the efficiency of cloud services. The efficiency of cloud services is calculated and the impact of the functional and the non-functional cloud attributes on efficiency is pointed. Moreover, the IaaS services are evaluated as efficient and inefficient.

This thesis fills a gap in literature, since research about the relation between price and quality in the cloud environment, is in its infancy. Therefore, the pricing models have been developed, by taking into consideration non-functional attributes. Researchers can modify and extend the proposed models, by adding new requirements, and new cloud attributes, thus different aspects of cloud quality can be presented and their impact on the price can be examined. Furthermore, this thesis evaluates cloud services as efficient units, by using DEA as a powerful decision making tool. This will assist researchers examine the performance evaluation of cloud provides. Also, different input and output variables can be used, forming a different approach. In addition, the proposed model can be applied to PaaS and SaaS or other systems.

Inspection of relative literature reveals that especially users ‘aspect is rarely highlighted. In this context, the users' perspective may be a useful tool for cloud providers to improve their services and be compliant with the users' preferences, aiming at profitability improvement. Furthermore, since providers' aspect reveals the concept behind the adopted pricing model, the potential users will have the opportunity to negotiate better discounts or gain an optimal usage of cloud services. Furthermore the cost effective cloud solutions are indicated and users can safely choose the solution that offers the maximum service in a reasonable price.

Pricing a product is one of the most important decisions an organization makes. Thus, this thesis develops different approaches to price optimization. Its results can be a powerful tool for providers to improve their services that do not keep up with users' priorities, understand what end users' value and take their preferences into consideration, expecting profitability improvement. In cloud market the competition is fierce, but prices do not converge to the same level because of price-quality differentiation Figure 38 presents thesis's contribution.

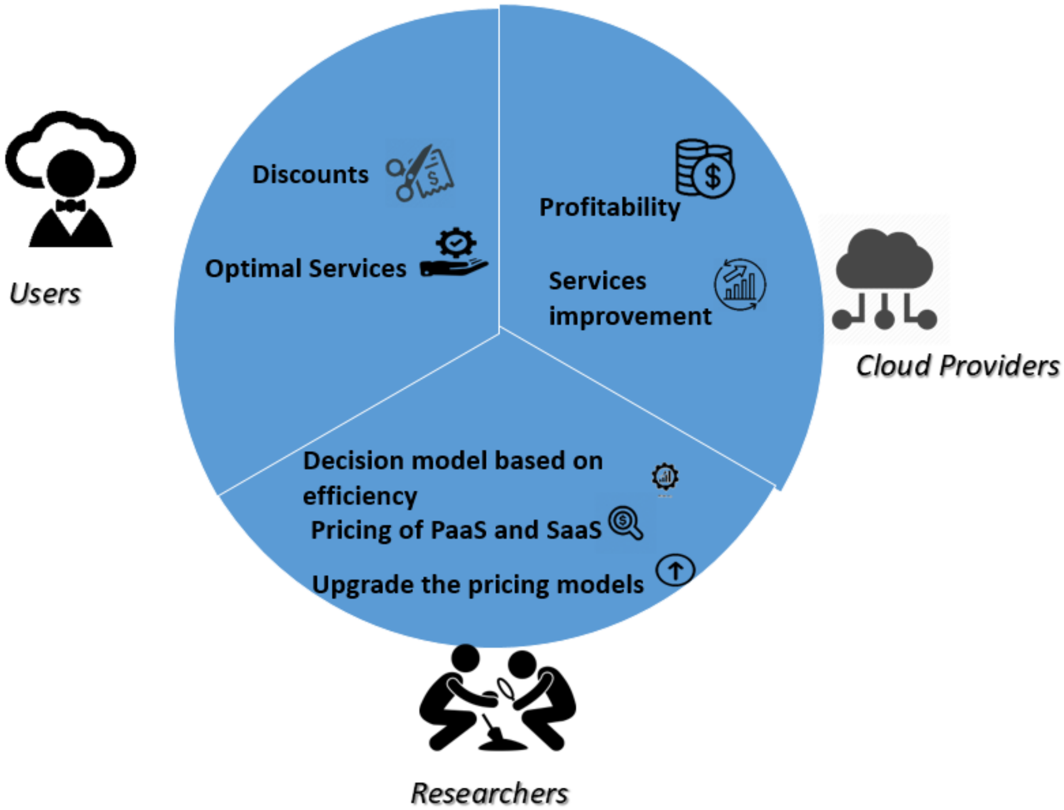

Figure 38 Thesis's contribution

8.5 Future directions

Cloud providers and cloud users constitute the main contracting parties of the cloud environment. The current thesis examines the pricing of IaaS services, highlighting the users' and providers' aspect. Pricing models are proposed, developed by using economic methods, such as Hedonic Price Index, Structural Equation Model, Data Envelopment Analysis and PairWise Comparison framework. Furthermore, the contribution of the functional and non-functional requirements in the shaping of the final price is pointed out.

Cloud computing also includes cloud broker. Cloud broker is an essential entity that manages the use, performance and delivery of cloud services and negotiates relationships between cloud providers and cloud end users. It rents a number of reserved VMs from cloud providers with a good price and offers them to users on an on-demand basis at a cheaper price than cloud providers and also generates more predictable demand flow for cloud providers.

A broker makes profit by matching buyer's demands with seller's supplies. The broker uses a variety of methods to achieve a best price between these parties, and typically makes a profit by either taking a commission fee from any completed deal, or by varying the broker's spread, or some combination of fees and spread. The spread is the difference between the price at which a broker buys from sellers and the price at which it sells to buyers (Rogers and Cliff, 2012).

The pricing schemes that examine brokers' profitability are studied and reviewed in (Filiopoulou et al., 2016). As a forthcoming research the pricing of the Internet of Things (IoT) broker constitutes an innovative concept, which will play an important role in the IoT networks. The Internet of things (IoT) is the internetworking of physical devices embedded with electronics, software, sensors, actuators, and network connectivity that enables these objects to collect and exchange data (Gubbi et al., 2013). The development of the IoT ecosystem demands collaboration among businesses, governments and technology industry. IoT networks generate massive amounts of data and cloud computing delivers these data to their destinations. Infrastructure services and communications can build solutions, by providing solutions for the management of the gathered data.

It is expected that the evolution of the IoT involves a significant increase of data, services, applications and interactions among different objects and thus the need for an intermediary acting as a middleware layer on a relational environment between all IoT entities. The Broker of the Internet of Things (BIoT), as the intermediary entity in the future IoT networks, was introduced in (Dede et al., 2019). BIoT is an evolution and a more complex business model than cloud broker and will hold an important role in future IoT networks. Even though BIoT must include computing infrastructure services and software solutions, it also includes telecommunication services, network access and consulting services to end users.

The pricing of IoT networks can be examined based on pricing schemes that are used into the current thesis. Furthermore, the profitability of BIoT can be examined, focusing on the factors that affect its profit and also proposing optimal IoT solutions that can lead to profit maximization.

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