JYVÄSKYLÄ STUDIES IN COMPUTING

278

Gabriella Laatikainen

Financial Aspects of Business Models

Reducing Costs and Increasing Revenues in a Cloud Context

JYVÄSKYLÄN YLIOPISTO

JYVÄSKYLÄ STUDIES IN COMPUTING 278

Gabriella Laatikainen

Financial Aspects of Business Models

Reducing Costs and Increasing Revenues in a Cloud Context

Esitetään Jyväskylän yliopiston informaatioteknologian tiedekunnan suostumuksella
julkisesti tarkastettavaksi yliopiston Agora-rakennuksen Lea Pulkkisen salissa
toukokuun 11. päivänä 2018 kello 12.

Academic dissertation to be publicly discussed, by permission of
the Faculty of Information Technology of the University of Jyväskylä,
in building Agora, Lea Pulkkinen hall, on May 11, 2018 at 12 o'clock noon.

UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2018

Financial Aspects of Business Models

Reducing Costs and Increasing Revenues in a Cloud Context

JYVÄSKYLÄ STUDIES IN COMPUTING 278

Gabriella Laatikainen

Financial Aspects of Business Models

Reducing Costs and Increasing Revenues in a Cloud Context

UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2018

Editors
Marja-Leena Rantalainen
Faculty of Information Technology, University of Jyväskylä
Pekka Olsbo, Ville Korkiakangas
Publishing Unit, University Library of Jyväskylä

Cover painting: “Swallows in September” by Erzsébet Brittich, acryl/canvas, 50x70 cm.

Permanent link to this publication: http://urn.fi/URN:ISBN:978-951-39-7408-4

URN:ISBN:978-951-39-7408-4
ISBN 978-951-39-7408-4 (PDF)

ISBN 978-951-39-7407-7 (nid.)
ISSN 1456-5390

Jyväskylä University Printing House, Jyväskylä 2018

ABSTRACT

Laatikainen, Gabriella
Financial aspects of business models: Reducing costs and increasing revenues in a cloud context
Jyväskylä: University of Jyväskylä, 2018, 92 p. (+included articles)
(Jyväskylä Studies in Computing
ISSN 1456-5390; 278)
ISBN 978-951-39-7407-7 (nid.)
ISBN 978-951-39-7408-4 (PDF)

The emergence of cloud computing induces opportunities for software vendors and for organizations with great storage needs. Indeed, software companies have begun to adopt cloud technologies and offer their software as a service to customers instead of selling software products. As a result, their revenue models have changed, and the diversity and complexity of the resulting pricing models have created both opportunities and impediments to competition in the market. On the other hand, due to the exponentially growing volume of digital content, organizations have an increasing demand for storage and need to choose between private, public, and hybrid storage solutions. This decision requires consideration of various determinants; cost is one of the most vital factors. This dissertation investigates the impact of cloud computing technologies on the IT industry, with a focus on the financial aspects of business models. That is, this research uses quantitative, qualitative, and analytical-mathematical research methods, as well as simulations, to find ways to improve companies' financial performance by enhancing their pricing models and reducing their storage costs. In particular, this research contributes to the cloud pricing literature by proposing a pricing framework developed specifically for the cloud industry, by providing insights into the relationship between software architecture and pricing, and by providing a view on how cloud technology adoption has changed software pricing models. In addition, this research contributes to the cloud cost literature and to the concurrent sourcing literature by providing analytical models that capture the effects that various cost determinants have on the cost-efficiency of private versus public storage and the cost of hybrid storage. This research indicates that, in the case of exponentially growing storage demand, reestimating future needs and acquiring the necessary in-house infrastructure usually makes the private cloud more cost-effective than the public cloud; the total cost of hybrid storage decreases as well. In addition, this research sheds light on various details regarding storage cost reduction, such as the roles of volume uncertainty and volume variability in hybrid storage costs, the time point when reestimating hybrid storage needs results in the greatest cost benefits, and the magnitude of these achievable cost benefits.

Keywords: cloud computing, cloud storage, cloud business models, cloud pricing, cloud costs

Author Gabriella Laatikainen
Faculty of Information Technology
University of Jyväskylä
Finland

Supervisors Professor Dr. Pasi Tyrväinen
Faculty of Information Technology
University of Jyväskylä
Finland

Dr. Oleksiy Mazhelis
Data Analytics
Qvantel
Finland

Adjunct Professor Dr. Arto Ojala
Faculty of Information Technology
University of Jyväskylä
Finland

Reviewers Professor Dr. Peter Buxmann
Technische Universität Darmstadt
Germany

Assistant Professor Dr. Sami Hyrynsalmi
Tampere University of Technology
Finland

Opponent Professor Dr. Casper Lassenius
Aalto University
Finland

ACKNOWLEDGEMENTS

I would like to express my gratitude to many people who contributed to the work presented in this dissertation or supported me during my doctoral studies. First, I would like to thank my supervisors, Prof. Dr. Pasi Tyrväinen, Dr. Oleksiy Mazhelis, and Dr. Arto Ojala, who offered me guidance, help, and moral support. Professor Pasi Tyrväinen gave me the opportunity to start my doctoral studies and helped me continuously from the start until the end. I thank him for providing many brainstorming sessions and great conversations, quickly solving all of my practical issues, being a co-author in two of my articles in this dissertation, and supporting me in many other ways. I am extremely grateful for Dr. Oleksiy Mazhelis, who provided lots of help at various stages of the research, for teaching me so much about research and academic writing, as well as for showing the light at the end of the tunnel many times. It was an honor to work with him on many articles in this dissertation. Undoubtedly, without his continuous support, this thesis would not exist in this form. I would like to thank Dr. Arto Ojala for his help, guidance and many inspirational conversations during these years and especially for teaching me everything I know about qualitative research. I also thank him for his trust and help with contacts for data collection and for being a coauthor in two of my articles.

I would also like to thank Dr. Eetu Luoma for many inspirational conversations all these years and especially for lots of help that he provided as a coauthor of the quantitative study. In addition, I thank Dr. Mikko Rönkkö and Dr. Juhana Peltonen for performing the data collection for that article. I am grateful for Dr. Mikko Rönkkö also for spreading his enthusiasm about quantitative research methods and helping me to have some moments when suddenly all the values, stars and statistical jargon made sense.

I am grateful for the reviewers of this dissertation, Prof. Dr. Peter Buxmann and Dr. Sami Hyrynsalmi for the constructive comments and the evaluation of the work. I am honoured that Prof. Dr. Casper Lassenius acts as my opponent on the public defence.

I would like to thank Dr. Veikko Halttunen for his guidance related to my teaching duties and great conversations on different topics.

I am especially grateful for (soon-to-be) Dr. Tiina Koskelainen, with whom I could share my everyday joys and sorrows, for being someone whom I could always count on. She made these years much more enjoyable. Special thanks go to Teija Palonen for making my workdays so much brighter.

I thank Dr. Markus Salo for being open for research-related conversations, even during coffee breaks, and for his profound answers to questions on many matters.

It is impossible to enlist all the people that contributed to our great work community. I would like thank them all especially for refreshing lunch and coffee conversations and the productive work atmosphere.

I thank Erzsébet Brittich for painting this dissertation's cover picture, creating a bridge between my childhood and my current life. The view of the swallows sitting on the electric wires from Zerind, as well as fruit trees and clouds, has been imprinted on me since I was a little child.

I would also like to thank my friends for being part of my life during these years. Special thanks go to György Hingyi for the brainstorming conversation we had about cloud research issues before I started my doctoral studies.

Last but not least, I would like to thank my family for supporting me during these years. My parents, József Fazekas and Irén Fazekas, implanted in me a deep respect for science from my early childhood. They have motivated and supported me throughout my life and have allowed me to follow my (sometimes irrational) dreams and to pursue new challenges. I am deeply grateful and proud that they are my parents. My greatest thanks also go to my brother Gábor Fazekas for supporting me throughout my life.

I am especially grateful for Elina Pääkkönen and Petri Pääkkönen for their continuous support and help over the years, and for being the persons whom I could always count on. I am extremely lucky that they are part of our lives in Peuravuori. I thank also our dear godsons, Lauri and Oskari for bringing so much fun into my life.

I would like to thank Eija Laatikainen and Toivo Laatikainen for supporting me and helping so much during these years. Our children are very lucky to have them as grandparents.

Finally, my warmest gratitude goes to my husband, Antti Laatikainen, and to our children, Aaron and Anna. Without Antti, I would not have even started my PhD studies, and I would have stopped during the process many times. Antti motivated me to pursue my dreams and supported me day by day in various matters. Aaron and Anna have made these years meaningful and full of joy. I am happy and proud to be their mother; they are the best kids ever.

Jyväskylä, 20.3.2018
Gabriella Laatikainen

LIST OF INCLUDED ARTICLES

1. Laatikainen, G., Ojala, A., & Mazhelis, O. (2013). Cloud services pricing models. In *International Conference of Software Business* (pp. 117–129). Springer, Berlin, Heidelberg.
2. Laatikainen, G., & Ojala, A. (2014). SaaS architecture and pricing models. In *2014 IEEE International Conference on Services Computing (SCC)* (pp. 597–604). IEEE.
3. Laatikainen, G., & Luoma, E. (2014). Impact of cloud computing technologies on pricing models of software firms–Insights from Finland. In *International Conference of Software Business* (pp. 243–257). Springer, Cham.
4. Laatikainen, G., Mazhelis, O., & Tyrväinen, P. (2014). Role of acquisition intervals in private and public cloud storage costs. *Decision Support Systems*, 57, 320–330.
5. Laatikainen, G., Mazhelis, O., & Tyrväinen, P. (2016). Cost benefits of flexible hybrid cloud storage: Mitigating volume variation with shorter acquisition cycle. *The Journal of Systems & Software*, 122, 180–201.

FIGURE

FIGURE 1 The scope of the research 40
FIGURE 2 Cloud service pricing framework 57
FIGURE 3 The impact of architecture on pricing models 60

TABLE

Table 1 Studies on cost structure of cloud infrastructure 31
Table 2 Cost-based metrics used for the cost-based investigation of different deployment options 32
Table 3 Research objectives and summary of key findings and contribution 63

CONTENTS

ABSTRACT
FOREWORD / PREFACE / ACKNOWLEDGEMENTS
FIGURES AND TABLES
LIST OF INCLUDED ARTICLES
CONTENTS

1 INTRODUCTION ... 11
1.1 Cloud computing ... 11
1.2 Pricing models of Software-as-a-Service companies ... 12
1.3 Storage cost reduction ... 13
1.4 Summary ... 16

2 THEORETICAL BACKGROUND ... 18
2.1 Financial aspects of business models ... 18
2.1.1 Business models ... 18
2.1.2 Financial aspects of business models: cost and revenue model ... 20
2.2 Cloud computing and Software-as-a-Service ... 21
2.2.1 General terms in cloud computing ... 21
2.2.2 Hybrid cloud computing infrastructure ... 22
2.2.3 Software-as-a-Service and Software-as-a-Service providers ... 25
2.3 Pricing and cost in a cloud context ... 27
2.3.1 Software-as-a-Service pricing ... 27
2.3.2 Cost factors in cloud infrastructure ... 30
2.3.3 Cloud storage and cost-reduction approaches ... 33
2.4 Concurrent sourcing and the hybrid cloud infrastructure as an instantiation of it ... 34
2.5 Summary: research gaps in literature on pricing models and cost reduction approaches in a cloud context ... 37

3 THE SCOPE OF THE RESEARCH AND RESEARCH METHODOLOGY 39
3.1 The scope of the research and research objectives ... 39
3.2 Research approach ... 41
3.3 Content analysis based on information collected from companies' web pages ... 42
3.4 Qualitative research method: multi-case study ... 43
3.5 Quantitative research method: survey ... 44
3.6 Analytical mathematical research ... 46
3.7 Simulations ... 46

4 OVERVIEW OF THE ARTICLES ... 48
4.1 Article I: "Cloud Services Pricing Models" ... 48
4.2 Article II: "SaaS architecture and pricing models" ... 49

4.3 Article III: "Impact of cloud computing technologies on pricing models of software firms – Insights from Finland" 50
4.4 Article IV: "Role of Acquisition Intervals in Private and Public Cloud Storage Costs" 51
4.5 Article V: "Cost benefits of flexible hybrid cloud storage: Mitigating volume variation with shorter acquisition cycle" 52
4.6 Contributions to joint articles.. 54

5 RESULTS AND CONTRIBUTIONS 55
5.1 Results 55
5.1.1 Increasing revenues of SaaS companies...................................... 55
5.1.2 Reducing cloud storage costs 61
5.2 Contributions.. 62
5.2.1 Theoretical contributions 64
5.2.2 Practical contributions... 65
5.3 Limitations and further studies 68

YHTEENVETO (FINNISH SUMMARY)... 70

ÖSSZEFOGLALÓ (HUNGARIAN SUMMARY)... 71

REFERENCES.. 72

1 INTRODUCTION

This chapter describes this dissertation's research area, introduces the main concepts, and highlights the research gaps that this dissertation focuses on. It also includes an outline of the dissertation's structure.

1.1 Cloud computing

Cloud computing can be seen as computing resources that are flexible, shared, and accessible from the internet (Babcock, 2010; Durkee, 2010). The cloud market is growing extraordinarily rapidly, and this trend has been forecast to continue (Columbus, 2015; International Data Corporation, 2015). The world has embraced the "everything as a service" concept in which organizations buy resources from cloud providers rather than purchasing, provisioning, and maintaining their own resources (Banerjee et al., 2011). These rented resources may include (1) raw processing, storage, networks, and other computing resources (i.e., infrastructure-as-a-service, *IaaS*); (2) development environments for deploying applications to the cloud (i.e., platform-as-a-service, *PaaS*); and (3) applications running on the provider's infrastructure, which are usually accessible through a web browser (i.e., software-as-a-service, *SaaS*; Durkee, 2010; Lenk, Klems, Nimis, Tai, & Sandholm, 2009; Mell & Grance, 2011). Organizations can choose from among various cloud deployment models: (1) *public*, in which resources are available to the general public or to a large industry group but are owned by a cloud provider; (2) *private*, in which an organization exclusively operates the cloud infrastructure; (3) *hybrid*, which combines private and public cloud infrastructure resources; and (4) *community*, in which several organizations share the cloud infrastructure (Mell & Grance, 2011).

The emergence of cloud technologies has impacted all areas of information technology (*IT*), including supply, composition, and consumption, and has transformed the businesses of both software vendors and organizations that use

IT infrastructure (Kaltenecker, Hess, & Huesig, 2015). This dissertation focuses on two partially overlapping sets of organizations: (1) software companies that adopt cloud technologies and change their pricing models and (2) organizations that use IaaS to reduce costs. First the impact of cloud computing technologies on the software industry is overviewed with a focus on pricing.

1.2 Pricing models of Software-as-a-Service companies

Indeed, the disruptiveness of cloud technologies is visible in the software industry. Traditional software product companies offer similar software applications (Cusumano, 2008), but SaaS providers supply internet-based software functionalities to end users via subscription (Benlian & Hess, 2011; Marston, Li, Bandyopadhyay, Juheng Zhang, & Ghalsasi, 2011). Thus, SaaS software is different from traditional software products not only because it uses cloud technologies but also because it utilizes a different revenue logic than is used in traditional, licensed software (Ojala, 2016a; Stuckenberg, Fielt, & Loser, 2011; Tyrväinen & Selin, 2011). As a result, software companies have changed their revenue models and shifted from product revenues toward service revenues (Cusumano, 2008; Popp, 2011).

In fact, the pricing models research is exceptionally important, since appropriate pricing strategies and well-defined, transparent pricing models can increase organizations' revenues by attracting various customer segments, influencing customers' behavior, and differentiating their own value propositions from those of their competitors (Anandasivam & Premm, 2009; Iveroth et al., 2013; Piercy, Cravens, & Lane, 2010; Popp, 2011). Pricing is a powerful strategic tool in managers' hands, and innovation in pricing is a source of competitive advantage (Hinterhuber & Liozu, 2014). However, choosing suitable pricing strategies is a capability that organizations need to develop and the identification of pricing practices in various markets needs more research (Dutta, Zbaracki, & Bergen, 2003; Hallberg, 2017; Hinterhuber & Liozu, 2017; van der Rest, Roper, & X. L. Wang, 2018).

Indeed, research on pricing has been neglected, and managers often make ad hoc pricing decisions (Hinterhuber, 2004; Hinterhuber & Liozu, 2014). This is a problem especially in software and SaaS business, because of the complexity and diversity of pricing models, as the pricing models of software companies are complicated, constantly changing, and difficult to compare (Cusumano, 2007). In the literature, many works have summarized the various aspects of pricing models in general (e.g., Iveroth et al., 2013) and of software pricing in particular (e.g., Lehmann & Buxmann, 2009). These pricing aspects are related to, among other factors, the type of price formation (cost-based, value-based, or competition-oriented), the length of time when the customer can use the software (buying, renting, or pay-per-use), price discrimination, price bundling, the ability for buyers and sellers to influence the price (through, e.g., price lists, negotiations, auctions, or exogenous pricing), and the type of pricing strategy (e.g., penetration, skimming, free, or premium pricing) (Iveroth et al., 2013; Lehmann & Buxmann, 2009). However, with respect to cloud characteristics, the current literature does not include any systematic pricing frameworks that researchers can use as a basis for further studies or that managers can use to develop the most appropriate pricing models and to discuss various aspects related to pricing.

Due to the SaaS delivery model and its ability to introduce new pricing-model characteristics more easily than in the traditional, software-product model, decisions on pricing in SaaS must be made in the early phases of development (Kittlaus & Clough, 2009). For example, software usage must be measured in the usage-dependent pricing model, which has an impact on the software's design. Software architecture and pricing are interrelated; besides the impact that the pricing model has on the architecture, the architecture may also enable or limit certain the pricing characteristics. One example of how the software architecture limits the pricing model is when, due to software design, various service components cannot be offered and priced separately and must instead only be provided in a bundle. Although the relationship between a software architecture and its pricing model is important to understand, this topic has not yet been investigated in the literature.

The emergence of cloud technologies in a competitive market environment has induced changes in software organizations' business models (Battleson, West, Kim, Ramesh, & Robinson, 2016; Luoma, 2013; Ojala, 2016a). In the state-of-the-art literature, various studies have investigated these business-model changes (e.g., Cavalcante, Kesting, & Ulhøi, 2011; Demil & Lecocq, 2010; Van Putten & Schief, 2013; Voelpel, Leibold, & Tekie, 2004; Wirtz, Pistoia, Ullrich, & Göttel, 2016), with a particular focus on the impact that cloud computing technologies have had on software companies' business models (Boillat & Legner, 2013; Luoma & Nyberg, 2011; Luoma, Rönkkö, & Tyrväinen, 2012). However, the qualitative study by Ojala (2016a) is the only one to have investigated the changes that cloud adoption has caused in software businesses' revenue models. Thus, in the literature, there is a shortage of quantitative research on the impact that cloud adoption has had on pricing models in the software industry.

The emergence of cloud computing has had an impact not just on the software industry but also on all organizations that have great storage needs. This research area is outlined in the next section.

1.3 Storage cost reduction

In the new digital era, with its exponentially growing volume of digital content, the global need for storage capacity is rapidly increasing (Fulton, 2011; TwinStrata, 2013). To cope with the increasing demand for storage, organizations may decide between building and maintaining their own resources, renting storage resources from public cloud providers, or concurrently using both internal and external resources. Indeed, the decision on cloud adoption is complex and requires deep investigation (Senyo, Addae, & Boateng, 2018; Venters & Whitley, 2012). Decision makers should consider several factors, including cost, elasticity, data availability, security, data confidentiality and privacy, regulatory requirements, reliability, performance, integration with other services, personal preference, and added value (Khajeh-Hosseini, Greenwood, Smith, & Sommerville, 2012). In addition to analyzing the constraints and risks related to possible cloud adoption, the benefits of this adoption should be taken into consideration as well. These benefits include a greater focus on core competencies and quality improvements, enhanced business flexibility, and access to skills and applications (Benlian & Hess, 2011). However, among these benefits, cost savings are perceived as the most significant advantage of cloud adoption (Benlian & Hess, 2011). The extent of these expected cost benefits depends on the impact of individual cost factors such as the prices of public and private storage, the charging interval, the intensity of data communications, and the predictability of demand increases (Khajeh-Hosseini et al., 2012; Mazhelis, 2012).

Public infrastructure providers usually apply pay-per-use pricing schemes in which customers pay only for resources that they actually use. However, these prices lead to a so-called utility premium; as a result, the unit prices of public capacity are usually more expensive than those for in-house solutions (Khajeh-Hosseini et al., 2012). For computing resources, organizations with random or periodic peak loads may find it financially more beneficial to use public resources despite this premium (Weinman, 2012). However, as opposed to the fluctuating computing capacity demand, for organizations whose stored data volume accumulates over time, the possible cost benefits of using public storage require more investigation.

Consequently, one of the most important factors in calculating the expected cost savings of cloud storage services is the *acquisition interval* (also called the demand reassessment interval or acquisition cycle). In this context, the acquisition interval is the time period during which the organization reassesses its storage needs and acquires additional resources if needed. This interval depends on the company's internal practices, on the predictability of storage demand growth, and on the in-house resource vendors' provisioning schedules, among other factors. Despite this interval's importance, its impact on the cost-efficiency of private vs. public cost, as well as on the overall cost in case of a hybrid cloud storage solutions has not been considered in the literature.

The popularity of hybrid cloud solutions has increased recently, and more than 67% of enterprises are choosing the hybrid strategy (RightScale, 2017). Indeed, the use of hybrid cloud solutions promises cost savings; flexibility; reduced risks regarding loss of data control; the ability to fulfill special requirements (e.g., performance, data availability and sensitivity, error traceability, and interoperability); the ability to comply with organizational, governance, and legal constraints; and decreased vendor lock-in, among other benefits (Desair, Joosen, Lagaisse, Rafique, & Walraven, 2013; Juan-Verdejo &

Baars, 2013; Mazhelis & Tyrväinen, 2012; Phaphoom, X. Wang, Samuel, Helmer, & Abrahamsson, 2015; Weinman, 2012). However, organizations that choose the hybrid infrastructure face challenges related to partitioning their applications (deciding which components or jobs stay in the private cloud and which are migrated to the public one; e.g., Fan, W.-J. Wang, & Chang, 2011; Hajjat et al., 2010; Huang & Shen, 2015), the time and process of migration (e.g., Fan et al., 2011), cloud bursting (when the workload exceeds a particular threshold, causing the surplus load to be placed in the public cloud infrastructure; e.g., Fadel & Fayoumi, 2013), automatic resource provisioning (mapping application requests to the physical resources on the fly; e.g., Calheiros, Ranjan, Beloglazov, De Rose, & Buyya, 2011), and scheduling (scheduling the application's execution across the distributed resources on the fly; e.g., Chopra & Singh, 2013a). Furthermore, in the hybrid cloud literature, one of the most salient research areas is the search for the most cost-efficient mix of internal and external resources (Kashef & Altmann, 2012; Weinman, 2012).

The concurrent sourcing phenomenon (i.e., concurrently buying and producing the same good or service) has lately been a focus of the literature on strategic and operations management (Freytag & Kirk, 2003; Water & Peet, 2006; Weigelt & Sarkar, 2012) and information systems (IS) (Gregory, Beck, & Keil, 2013; Kotlarsky, Scarbrough, & Oshri, 2014; Lacity, Solomon, Yan, & Willcocks, 2011). Explaining the reasons behind the use of concurrent sourcing has become one of the most important research areas in these domains. Various theoretical explanations and empirical findings have revealed that cost savings is one of the main drivers of this phenomenon (Heide, Kumar, & Wathne, 2013; Lacity, Khan, Yan, & Willcocks, 2010). Indeed, one of the theoretical explanations stems from transaction cost theory and neoclassical economics that claim that, in cases in which organizations face *volume uncertainty* (i.e., difficulty in accurately estimating the volume of the demand), the use of this governance form may result in cost reductions (Adelman, 1949; Mols, 2010; Parmigiani, 2003; Puranam, Gulati, & Bhattacharya, 2013). That is, in case involving fluctuating and/or unpredictable demand, the risk from diseconomies of scale due to unutilized surplus capacity may be reduced through the use of in-house resources for high-probability components while serving the peak demand with public resources (Heide, 2003; Puranam et al., 2013). Thus, volume uncertainty is an important factor in determining the cost savings that are achievable through the use of concurrent sourcing; however, the empirical results regarding the role of volume uncertainty in concurrent sourcing are contradictory (Krzeminska, Hoetker, & Mellewigt, 2013; Parmigiani, 2003). In addition, serving the peak demand with public resources could also bring about financial benefits in the case of *volume variability* (i.e., natural variations such as seasonal fluctuations; Puranam et al., 2013); however, the role of volume variability has not been explicitly considered in the concurrent sourcing literature. In this dissertation, volume uncertainty and volume variability together are referred to as *volume variation.*

The hybrid cloud infrastructure can also be seen as an instantiation of concurrent sourcing in which infrastructure needs are both served in-house and bought from public providers simultaneously. However, studying the hybrid cloud as a form of concurrent sourcing has attracted little attraction from IS researchers; the related studies on concurrent IT sourcing by Tiwana and Kim (2016) and on the economic aspects of hybrid cloud by Mazhelis and Tyrväinen (2012) are the only ones in this research area. Meanwhile, in the literature for both concurrent sourcing and the hybrid cloud, the key research issues include the cost-optimal mix of internal and external resources and volume uncertainty's role in cost savings and in cost-reduction mechanisms (Agarwala, Jadav, & Bathen, 2011; Altmann & Kashef, 2014; Mazhelis & Tyrväinen, 2012; Puranam et al., 2013; Sako, Chondrakis, & Vaaler, 2013; Trummer, Leymann, Mietzner, & Binder, 2010; Weinman, 2012). All these issues warrant further investigation and are addressed in this dissertation.

1.4 Summary

In summary, cloud computing and SaaS have induced big changes in the IT industry and in the organizations that use IT (Armbrust et al., 2010; Choudhary & Vithayathil, 2013). Even though researchers are paying increasing attention to the cloud phenomenon, many unresolved matters remain. In general, there is a need for a better understanding of cloud computing's business aspects, particularly the pricing models and cost factors related to cloud capacity (Cusumano, 2007; Marston et al., 2011; Schramm, Wright, Seng, & Jones, 2010; Schwarz, Jayatilaka, Hirschheim, & Goles, 2009; Venters & Whitley, 2012). To address these research gaps, this dissertation focuses on various financial aspects of cloud services with the aim of helping organizations to (1) increase their revenues by developing suitable pricing models that are in harmony with their value propositions and software architecture, thus ensuring the firms' positions in the competitive market and to (2) minimize their cloud storage infrastructure costs by giving more insights into the role that acquisition interval plays in the cost-efficiency of the private and public clouds as well as the effects that both acquisition intervals and volume variation have on hybrid cloud storage costs. The current dissertation (1) develops a pricing framework especially for the cloud industry, (2) investigates the interrelations between the SaaS architecture and its pricing model, (3) examines how software firms have changed their pricing models due to their adoption of cloud computing technologies, (4) studies the cost-efficiency of private vs. public storage, and (5) investigates how hybrid cloud storage costs can be reduced under conditions of volume uncertainty.

The structure of this dissertation is as follows. The next chapter outlines the related works regarding cloud computing and SaaS, hybrid cloud infrastructure, concurrent sourcing and the financial aspects (such as pricing and cost) of the cloud computing business models. In Chapter 3, the research's scope and methodology are presented. The included articles are overviewed in Chapter 4, and the dissertation ends with results and contributions in Chapter 5.

2 THEORETICAL BACKGROUND

The theoretical background for this dissertation is drawn from the extant literature on business models, cloud computing, SaaS, cloud storage, hybrid cloud, concurrent sourcing, cloud pricing, and cloud infrastructure costs. The following subsections provide an overview of the state-of-the-art literature in these areas.

2.1 Financial aspects of business models

2.1.1 Business models

During recent decades, researchers have increasingly focused on business models, mostly because, despite this concept's importance, it has no consistent definition in the literature, there is no clarity on the concept's purpose and on the right of the business model approach to exist, and the term includes a multitude of aspects (George & Bock, 2011; Kannisto, 2017; Luoma, 2013; Porter, 2001; Wirtz et al., 2016; Zott, Amit, & Massa, 2011). However, the literature described below shares a similar conceptual understanding.

A business model is an abstract concept; it can be seen as a representation of a company or as a tool that provides a picture of a firm's competitiveness (Amit & Zott, 2001; Teece, 2010; Wirtz et al., 2016). Thus, researchers' actual focus has included both internal and competitive views of business models (Osterwalder, Pigneur, & Tucci, 2005).

The term *business model* is an independent concept, and it differs from the terms strategy, organization theory, business planning, and business process model (Al-Debei & Avison, 2010; Amit & Zott, 2001; Casadesus-Masanell & Ricart, 2010; Heikkilä, Tyrväinen, & Heikkilä, 2010; Rajala & Westerlund, 2007; Seddon, Lewis, Freeman, & Shanks, 2004. Strategy involves a vision, and a business model is only one result of a strategy (Casadesus-Masanell & Ricart, 2010). Business models can be seen as links between future planning (strategy) and operative implementation (process models), as business models provide the means for strategy implementation (Al-Debei & Avison, 2010; Wirtz et al., 2016).

In addition to the static view of business models, there is a dynamic perspective in which business models are seen as likely to change (Wirtz et al., 2016). Changes in a business model may occur "between and within the core model components"(Demil & Lecocq, 2010, p. 234) and can be related to various phases of the lifecycle in a business model, including creation, extension, revision, and termination (Cavalcante et al., 2011). Business model changes can include various dimensions, including evolutionary changes in the model itself (Demil & Lecocq, 2010) and business model innovations (Voelpel et al., 2004); they also might affect various levels (Van Putten & Schief, 2013; Wirtz et al., 2016).

These changes can occur in response to external and/or internal influences. Technological advances are a key external factor that leads to changes in business models (Bharadwaj, El Sawy, Pavlou, & Venkatraman, 2013; Casadesus-Masanell & Ricart, 2010; Chesbrough & Rosenbloom, 2002; Kamoun, 2008; Ojala, 2016b; Timmers, 1998; Wirtz, Schilke, & Ullrich, 2010). In addition, changes in the business environment can force companies to update their business strategies and processes (Lehmann-Ortega & Schoettl, 2005; Ojala, 2016b; Osterwalder et al., 2005; Teece, 2010). Besides the external influences, the need for business model changes can also come internally. A company's employees can design, implement, and change its business models based on their perception of the firm's environment (Cavalcante et al., 2011; Chesbrough & Rosenbloom, 2002; Demil & Lecocq, 2010). As a consequence, the elements of business models are interrelated, and changes in any component can cause changes in others (Demil & Lecocq, 2010; Lehmann-Ortega & Schoettl, 2005).

In this dissertation, a business model is understood to be a conceptual model of a business: a description of how a company organizes itself, operates, and creates value; that changes over time due to external and internal forces (Baden-Fuller & Morgan, 2010; Casadesus-Masanell & Ricart, 2010; Luoma, 2013; Magretta, 2002; Osterwalder et al., 2005; Teece, 2010; Wirtz et al., 2016).

Business models are often viewed from a component-oriented perspective. Despite the business models' importance, researchers have not formed a consensus regarding either the core components of business models or their level of abstraction (Luoma, 2013). Business models can include strategic components (e.g., strategy, resources, and network), customer and market components (e.g., customers, value propositions, and revenues), and value-creation components (e.g., service provision, procurement, and finances) (Wirtz et al., 2016). Not all of these aspects can be presented in this dissertation, so the following subsection focuses on the financial aspects of business models, as is required for the topic of this dissertation.

2.1.2 Financial aspects of business models: cost and revenue model

One of the core business parameters that most researchers agree on is the *value proposition*, which incorporates the product and/or service portfolio (Chesbrough & Rosenbloom, 2002; Demil & Lecocq, 2010; Magretta, 2002; Osterwalder et al., 2005;). The value proposition refers to the value that the organizations' products or services create for the target customers (Chesbrough & Rosenbloom, 2002; Demil & Lecocq, 2010). The value proposition involves identifying a customer segment, the products or services that are offered to that segment, and the way in which the offer is marketed to that segment (Demil & Lecocq, 2010; Luoma, 2013).

In this dissertation, the term *financial aspects* refers to Osterwalder's Business Model Canvas, in which the financial aspects of business models include the company's profit- or loss-making logic (Osterwalder, 2004). Porter (1980) argues that "a firm is profitable if the value it commands exceeds the costs involved in creating the product" (p. 38). Thus, financial aspects determine the firm's ability to survive its competition (Demil & Lecocq, 2010); these aspects are in compliance with the business's economic requirements.

Even though its terminology differs in the research, the financial model typically consists of revenue-logic and cost-structure components (Boons & Lüdeke-Freund, 2013; M. Morris, Schindehutte, & Allen, 2005; Schief & Buxmann, 2012; Teece, 2010; Zott et al., 2011). In this dissertation, we use the term *revenue logic* (or *revenue model*) to describe how companies capture value; in other words, revenue logic is a plan for ensuring financial revenue generation by offering value to customers (Lehmann-Ortega & Schoettl, 2005; Mahadevan, 2000). Thus, this concept is a top-level description of a business's revenue sources and of the way in which the firm generates revenue by turning value into income (Rajala, Rossi, & Tuunainen, 2003; Saarikallio & Tyrväinen, 2014). On the other hand, in this dissertation, the term *pricing model* refers to an operational description of how revenues are collected.

To make a business profitable, both revenues and costs have to be investigated. A *cost model* is related to the business's value architecture (Lehmann-Ortega & Schoettl, 2005) and includes all the cost factors that contribute to value creation, including the running of various organizational activities and the acquisition, development, and integration of resources (Demil & Lecocq, 2010).

When creating value, companies can achieve competitive advantages by applying innovative business models (Chesbrough, 2007; Johnson, Christensen, & Kagermann, 2008). Structural changes in costs and/or revenues are the first sign of business-model evolution (Demil & Lecocq, 2010). Indeed, reforming a financial model can lead to an increase in revenue (Lehmann-Ortega & Schoettl, 2005). For example, using various pricing methods, such the free model, product/service bundling, or option pricing could help a company target new customers who have varied levels of willingness to pay (Mahadevan, 2000). Another way to improve a firm's financial status is to reduce the costs of value creation. This can be achieved, for example, by reducing transaction costs or customer search costs, or through the disintermediation of the supply chain (Mahadevan, 2000).

2.2 Cloud computing and Software-as-a-Service

2.2.1 General terms in cloud computing

Cloud computing is a multifaceted phenomenon that emerges from two strands: technological innovations and service-based business perspectives (Armbrust et al., 2010; Etro, 2009; Venters & Whitley, 2012). The most widely used technical definition of *cloud computing* is from the US National Institute for Standards and Technology: "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 & Grance, 2011). Cloud computing technology has five essential characteristics: (1) on-demand self-service, (2) broad network access, (3) resource pooling, (4) rapid elasticity, and (5) measured service (Mell & Grance, 2011).

Cloud computing services can be set up according to various deployment models: (1) a *public cloud* is available to the general public or a large industry group and is owned by a cloud provider, (2) a *private cloud* is operated exclusively for an organization, (3) a *hybrid cloud* is a combination of simultaneously used private and public cloud infrastructure resources, and (4) a *community cloud* is an infrastructure shared by several organizations (Mell & Grance, 2011).

Cloud services can be offered in a wide variety (Venters & Whitley, 2012). Based on the type of service and on the architectural view, the following service layers have been widely adopted in the literature: (1) *IaaS* provides raw processing, storage, networks, and other computing resources; (2) *PaaS* provides development environments for deploying applications to the cloud; and (3) *SaaS* provides applications that run on the provider's infrastructure and that are usually accessible through a web browser (Durkee, 2010; Lenk et al., 2009; Mell & Grance, 2011).

Cloud computing relies on certain core technologies that allow the cloud resources to be pooled together so that they can serve multiple clients. These technological enablers are virtualization, multitenancy, web service, and configurability (Dillon, Wu, & Chang, 2010; Marston et al., 2011).

Through *virtualization*, a logical grouping of a subset of computing resources (e.g., raw computing, storage, and network resources) can be made accessible to users via abstract interfaces (Marston et al., 2011). Virtualization is aimed at supporting the seamless provisioning of resources while keeping the location of the physical resources hidden from users (Bittencourt & Madeira, 2011). It can be realized in a form of a virtual machine, which represents an isolated execution environment that emulates the underlying computing platform; the virtual machine has its own operating systems, applications, and network services (Smith & Nair, 2005). As a result, users can flexibly install, configure, and maintain applications without the need to physically access the hosts (Foster, Zhao, Raicu, & Lu, 2008).

In a *multitenant* architecture, a single instance of common information (code and data) is shared with multiple tenants (Bezemer & Zaidman, 2010). This reduces the number of executed instances and thus minimizes an application's memory footprint, thereby improving operational efficiency (Cai, Wang, & Zhou, 2010; Marston et al., 2011). In addition to the requirements of shared hardware resources, shared applications, and shared database instances, Bezemer, Zaidman, Platzbeecker, Hurkmans, and Hart (2010) also require multitenant software to have a high degree of configurability in look and feel and in workflow. Some researchers consider multi-instancy to be a form of multi-tenancy (Guo, W. Sun, Huang, Z. H. Wang, & Gao, 2007) in which a vendor hosts separate instances for each customer within shared hardware (Guo et al., 2007; Zhu & Jing Zhang, 2012).

In this context, the term *web service* refers to communication using the HTTP protocol; in a web service, customers use an application via a browser (Marston et al., 2011). On the other hand, *configurability* represents the possibility for users to modify an application's appearance and behavior (through metadata services) to meet their needs. These configuration changes can include the user interface (colors, graphics, fonts, logos, etc.), workflow and business processes, or extensions of the data model and access control (Chong & Carraro, 2006).

For some companies, using both internal and external cloud resources is the best solution. The literature on the hybrid cloud computing infrastructure is outlined below.

2.2.2 Hybrid cloud computing infrastructure

The adoption of the hybrid cloud promises a number of benefits to the adopting organizations; some of these benefits are outlined below. First, the use of a hybrid cloud in organizations is often justified economically since, compared with relying on the public cloud infrastructure alone, using multiple sources to serve the demand may reduce the total costs by increasing the utilization rate of the local IT infrastructure and by decreasing the use of public cloud resources (Mazhelis & Tyrväinen, 2012; Weinman, 2012). By using public and private resources in concert, the organization may also mitigate the risks of losing the control over its data and hence fail to fulfil its requirements regarding performance, data sensitivity, availability, error traceability, and interoperability, as well as failing to comply with the related organizational, governance, contractual, and legal constraints (Juan-Verdejo & Baars, 2013; Phaphoom et al., 2015). Furthermore, organizations may choose hybrid solutions to decrease vendor lock-in and to reduce the dependency on the availability of a single cloud (Desair et al., 2013). Finally, in some cases, organizations may want to avoid taking the risk of migrating the entire system(s) to the public cloud, but instead follow a hybrid approach and migrate only a less-critical part of their system to the public cloud providers' premises (Cerviño, Rodríguez, Trajkovska, Escribano, & Salvachúa, 2013).

When adopting a hybrid cloud, the organization needs to *partition* its computing environment and decide which applications, components, or computing jobs must be kept in-house, and which ones have to be migrated to the public cloud (Fan et al., 2011; Hajjat et al., 2010; Huang & Shen, 2015; Juan-Verdejo & Baars, 2013). Partitioning is a complex task that can be done vertically (the component-based partitioning; i.e., splitting the application into the components to be hosted in-house and the components to be migrated to the cloud) and horizontally (the workload-based partitioning; i.e., replicating some components or the entire application on the cloud based on appropriate workload distribution mechanisms to handle the excess). The vertical partitioning may be challenging because the components may need to be ported to the public cloud's APIs; meanwhile, the horizontal partitioning may be challenging due to the need to maintain consistency among replicas of the stateful components (Hajjat et al., 2010; Tak, Urgaonkar, & Sivasubramaniam, 2011, 2013). Partitioning legacy enterprise applications is especially challenging (Ko, Jeon, & Morales, 2011). The migration and component placement can be done at different granularities, such as applications, components, virtual machines, jobs, tasks, bag-of-tasks, workflows, workloads, and so on [1] (Gutierrez-Garcia & Sim, 2015; Juan-Verdejo & Baars, 2013; Lilienthal, 2013; Mian, Martin, Zulkernine, & Vazquez-Poletti, 2012; Moschakis & Karatza, 2015; Vecchiola, Calheiros, Karunamoorthy, & Buyya, 2012).

In a hybrid environment, different policies are used to decide if the application or the workload is assigned to the private or public cloud. Aside from deciding what to migrate, the time and process of migration are to be considered (Fan et al., 2011; W.-J. Wang, Lo, Chen, & Chang, 2012). From a technical point of view, the application-specific functionalities and requirements have to be taken into account, such as complexity, performance, availability, traceability of errors, interoperability issues, data and system lock-in problems, and transaction delays due to migration (Fan et al., 2011; Hajjat et al., 2010; Juan-Verdejo & Baars, 2013; Khajeh-Hosseini, Sommerville, Bogaerts, & Teregowda, 2011; W.-J. Wang et al., 2012). Migrating some of the applications or components might also have economic, security, and privacy implications that need to be considered (Juan-Verdejo & Baars, 2013; Silva, Costa, & Oliveira, 2013). In some cases, usually when the workload is heterogeneous in nature, the

---

1 Each computing job consists of several independent tasks that can be executed in an arbitrary order. A workflow is a composition of interrelated tasks that form a distributed application. A workload is defined as the set of application requests or the amount of resources requested per time interval (e.g., the number of instances per hour) where the time interval is usually the minimum rent and billing time for public resources. Bag-of-Tasks (BoTs) applications are sets of multiple unconnected tasks with the possibility of parallel execution.

sensitive data and tasks with high performance requirements are assigned to the private infrastructure and less critical tasks tolerating occasional delays are placed to the public host instances (Hongli Zhang, Li, Zhou, Wu, & Yu, 2014). Alternatively, mostly in case of a homogeneous workload, the decision of the use of local or public resources may be decided on the fly, depending on the current load of the system (Mazhelis, 2012). In this case, *cloud bursting* is used; that is, if the workload exceeds a particular threshold, then the surplus load is placed into the public cloud infrastructure. Cloud bursting is used to minimize the costs or accelerate the execution of applications; thus, it offers the organizations good trade-offs between costs, availability, and performance (Fadel & Fayoumi, 2013; Shifrin, Atar, & Cidon, 2013). In cloud bursting, the main issue is determining the workload or the portion of the workload that has to be offloaded (Fadel & Fayoumi, 2013). The cost-optimal time of using public resources has been shown to be in inverse proportion with the premium charged by the public cloud provider (Mazhelis & Tyrväinen, 2011, 2012; Weinman, 2012). In addition, the cost-optimal time of using the public cloud is affected by the data communication overheads and the volume discounts (Mazhelis & Tyrväinen, 2011, 2012).

Rather than determining a suitable distribution of workload in advance, a related stream of research concentrates on the *automatic resource provisioning*; that is, the mapping of application requests to and the scheduling of the application execution on the distributed physical resources on the fly (Calheiros et al., 2011; Quiroz, Kim, Parashar, Gnanasambandam, & Sharma, 2009). Within this stream of research, several works study resource allocation that fulfills multiple quality of service (QoS) requirements or constraints, including accountability, agility, service assurance, cost, performance, security, privacy, and usability (Andrikopoulos, Song, & Leymann, 2013; Fadel & Fayoumi, 2013; Y. Sun, White, Eade, & Schmidt, 2015). Research efforts on optimal dynamic resource allocation have focused on cost-optimality alone (Cerviño et al., 2013; Charrada, Tebourski, Tata, & Moalla, 2012; Trummer et al., 2010), on cost-optimality coupled with target utilization and the response times of the private and public nodes (Bjorkqvist, Chen, & Binder, 2012), on the sensitivity of the data (Hongli Zhang et al., 2014; K. Zhang, Zhou, Chen, X. Wang, & Ruan, 2011), on the data volume and data popularity (Hui Zhang, Jiang, Yoshihira, Chen, & Saxena, 2009), on the bandwidth and data transfer time (Nadjaran, Sinnott, & Buyya, 2018), on the cost-optimality and performance requirements (Kasae & Oguchi, 2013), and on the customer and application context properties and cloud provider characteristics (Desair et al., 2013). Finally, a number of works addressed the problem of dynamic resource allocation and scheduling in case the requirements for the execution time and location are flexible. In particular, the *scheduling policies* have been studied based on cost-optimality and execution time constraints (Bittencourt & Madeira, 2011; Chopra & Singh, 2013a, 2013b; W.-J. Wang, Chang, Lo, & Lee, 2013), on the cost-optimality and the workload's resource requirements (Van den Bossche, Vanmechelen, & Broeckhove, 2010), on the deadline for application execution (Vecchiola et al., 2012), on the cost-optimality and communication and computational requirements of different task types (Shifrin et al., 2013), on the renewable energy supply (Lei, Tao Zhang, Liu, Zha, & Zhu, 2015), and on cost or time constraints (Bicer, Chiu, & Agrawal, 2012).

In the next subsection, an overview is presented on the literature on SaaS as well as SaaS firms.

2.2.3 Software-as-a-Service and Software-as-a-Service providers

In short, SaaS refers to *standardized* service using *cloud computing technologies* delivered *over the internet* and offered via *subscription* to the end users (Armbrust et al. 2010; Benlian & Hess 2011).

The SaaS model evolved from Application Service Provisioning (ASP), which was developed as an alternative to on-premise software in the late 1990s (Venters & Whitley, 2012; Xin & Levina, 2008). In the ASP model, software applications were offered as a service to the end users, and the hosting and maintenance of the software was outsourced to an ASP vendor (Benlian & Hess, 2011). Basically, the ASP model incorporates any software delivered over the internet that is based on a single-tenant architecture in which each customer has a customized version of the software in the ASP provider's server (Zhu & Jing Zhang, 2012). In contrast to SaaS, ASP users need some comprehensive IT expertise, and they may also pay an upfront IT investment fee for the application; this fee is separate from the subscription fee for the service (Desai & Currie, 2003; Kaltenecker et al., 2015).

On the other hand, in SaaS, multiple users are served with a single instance of a service with highly standardized functionalities (Benlian & Hess, 2011). This can be achieved by employing cloud computing technologies (virtualization, multitenancy, configurability, and web service; Chong & Carraro, 2006; Marston et al., 2011; Mell & Grance, 2011).

The SaaS model also refers to a subscription-based licensing model—software rental—where instead of a perpetual license fee, customers pay a subscription for the software that is developed, hosted, and maintained by the software firm (Choudhary, 2007). In this model, instead of owning it, the customer rents the software for a fixed period; therefore, the software is provided as a service rather than a product (Greschler & Mangan, 2002; Ojala, 2012).

One of the main research areas related to SaaS focuses on SaaS adoption, especially customers' reasons for SaaS adoption, and the benefits and risks related to it. Reasons for adoption include, among others, (1) the possible cost reductions due to economies of scale and scope; (2) the possibility to concentrate on their core business outcomes and consider customer value instead of managing technological assets, while software-related supporting tasks are outsourced; (3) the increased quality of service due to SaaS characteristics; (4) fast upgrades with no IT expertise needed; (5) and a more predictable budget due to a subscription-based revenue model instead of IT investments with possible over- or underprovisioning (Benlian & Hess, 2011; Choudhary, 2007; Currie, 2004; Greschler & Mangan, 2002; Grönroos, 2011).

On the other hand, SaaS adoption is associated with different risks, such as data availability, data security, data confidentiality, privacy, regulatory requirements, reliability, performance issues, integration with other services, personal preferences, and so on (Benlian & Hess, 2011; Desai & Currie, 2003; Khajeh-Hosseini et al., 2012). However, the benefits and the risks depend very much on the customers' needs and the relationship between the customer and the provider company (Jacobs, 2005).

Another stream of the SaaS literature deals with the supply side of SaaS, namely the *SaaS providers*. SaaS firms are software companies that are responsible for developing and maintaining their software and for providing it through the SaaS model to their customers. One of the main research streams regarding this area is the comparison between traditional on-premise software firms and on-demand SaaS companies. Software firms may encounter many benefits while moving to SaaS, such as an increase in economies of scale and scope, the possibility of targeting "the long tail of the market" (small companies and startups that may afford SaaS easier than software products; Chong & Carraro, 2006), a more predictable revenue model, faster updates, easier response to market changes, and so on (Benlian & Hess, 2011; Chong & Carraro, 2006; Choudhary, 2007; Greschler & Mangan, 2002; Kaltenecker et al., 2015). However, cloud-based business services providers also face risks (Ali, Warren, & Mathiassen, 2017).

During the transition to SaaS, impediments may appear related to the services (e.g., the service is misaligned with the customer's desired outcomes, the cost of market entry is unpredictable, possible legal issues), technology (e.g., dependence on IaaS/PaaS providers, added measures needed for ensuring security and privacy issues, immature technology issues), and process risks (e.g., challenges related to the transition from on-premise software to SaaS, problems related to the organization's current IT governance approach) (Ali et al., 2017; Battleson et al., 2016; Huyskens & Loebbecke, 2006; Kaltenecker et al., 2015; Venters & Whitley, 2012). Some of these risks are related to SaaS characteristics and the transformation of business (e.g., new market strategies are needed, the software is available online in different countries with different legislations, etc.), and some have come up because SaaS providers may rely on IaaS/PaaS providers.

Another stream of research studies SaaS firms' business and finance practices. Software product firms and SaaS companies have similar practices related to software development and the high up-front investments related to it (Benlian & Hess, 2011). However, SaaS providers and software product companies' businesses differ in many ways, such as (1) SaaS providers need capabilities and competencies for hosting (in case of in-house or hybrid solutions) and/or managing (in case of using public or hybrid cloud services) the IT infrastructure needed for the software, and their cost model also includes the cost of IT infrastructure; (2) SaaS firms use a subscription-based revenue model as a pricing logic, and due to this, they have shorter contracts with customers and different business activities, such as they invest more in software development to improve the quality of service; (3) SaaS providers target smaller customer segments with standard applications instead of targeting large companies with customer-specific software solutions and (4) their customer relationships are more direct and continuous (Chong & Carraro, 2006; Choudhary, 2007; Cusumano, 2008; D'souza, Kabbedijk, Seo, Jansen, & Brinkkemper, 2012; Kaltenecker et al., 2015; Schwarz et al., 2009; Stuckenberg et al., 2011).

Cloud computing offers many possibilities and instruments for innovating business and drives creativity (Willcocks, Venters, & Whitley, 2013). Therefore, cloud adoption induces changes to the software industry and the IT market (Iyer & Henderson, 2010; Weinhardt et al., 2009). SaaS providers may be smaller and relatively unknown compared to large companies with a well-known brand (Yao, 2002). Also, SaaS firms operate in a different value network compared to traditional software product companies: SaaS providers have a direct contact with their customers instead of having intermediaries, such as system integrators (Böhm, Koleva, Leimeister, Riedl, & Krcmar, 2010; D'souza et al., 2012; Leimeister, Böhm, Riedl, & Krcmar, 2010).

In the next section, the financial aspects of the business models are investigated in a cloud context.

2.3 Pricing and cost in a cloud context

2.3.1 Software-as-a-Service pricing

The literature on software and especially SaaS pricing has been studied through the lenses of different theories, such as transaction cost theory (Sundararajan, 2004; Susarla, Barua, & Whinston, 2009; Varian, 2000), network effect theory (Choudhary, Tomak, & Chaturvedi, 1998b; Haile & Altmann, 2016; Li, Cheng, Duan, & Yang, 2017; Guo & Ma, 2018), economics of digital goods (Lehmann & Buxmann, 2009), Porter's theory of competitive advantage (Ojala, 2016a), information theory (Lehmann, Draisbach, Buxmann, & Dörsam, 2012), system dynamics (Haile & Altmann, 2016), and game theory (e.g., Guo & Ma, 2018; Pal & Hui, 2013; L. Tang & Chen, 2017).

Studies reveal that finding the appropriate revenue model is the result of complex analysis that takes into account many aspects (Iveroth et al., 2013; Sundararajan, 2004). As software belongs to intangible information goods and SaaS is a service provided with the aid of software, pricing decisions should take into consideration the specific characteristics of information goods, such as indestructibility, transmutability, reproducibility, the presence of network effects in the software industry, and the software's possibility to cause lock-in (Bhargava & Choudhary, 2001a; Bontis & Chung, 2000; Choi, Stahl, & Whinston, 1997; Choudhary et al., 1998b; Shapiro & Varian, 1998; Valtakoski, 2015; Varian, 2000). However, software and SaaS may differ from other economic goods; for example, SaaS requires additional variable costs due to hosting and maintaining services (Lehmann & Buxmann, 2009).

One important aspect that guides pricing decisions is the applied information base during price formation (Iveroth et al., 2013; Lehmann & Buxmann, 2009). Price determination may be *cost-based*, *value-based* or *competition-oriented*, or a combination of these (Bonnemeier, Burianek, & Reichwald, 2010; Harmon, Raffo, & Faulk, 2005; Hinterhuber, 2004; Shipley & Jobber, 2001; Töytäri, Keränen, & Rajala, 2017). Due to the special cost structure of software, pricing cannot be done *solely* based on its *cost*—the cost rather determines the volume of profitable operations and not the price (Baur, Genova, Bühler, & Bick, 2014; Töytäri, Rajala, & Alejandro, 2015). On the other hand, variable cost factors (e.g., hosting and maintenance costs, costs related to improving the quality of service) may be taken into account when pricing SaaS (Lehmann & Buxmann, 2009). Value-based pricing takes into consideration the customer-perceived value of the software or SaaS (Baur et al., 2014; Bontis & Chung, 2000; Harmon, Demirkan, Hefley, & Auseklis, 2009). Since the customer's value perception is subjective, different, and unpredictable, value-based pricing may be difficult to implement (Hinterhuber, 2004; Töytäri et al., 2015). Finally, in software business, the competitive forces, such as the bargaining power of customers and providers, influence the providers' pricing decisions; thus, pricing is competition-oriented (Ojala, 2016a; Porter, 1980).

Another important aspect of pricing and revenue models is related to the length of time the user can use the offering (Iveroth et al., 2013; Lehmann & Buxmann, 2009). In the software business, the traditional revenue model has been *software licensing*, where customers buy a perpetual license for software that gives them the rights to use the software on a specific number of computers or processors or with unlimited usage rights (Bontis & Chung, 2000; Cusumano, 2010; Ferrante, 2006). However, with the emergence of cloud computing technologies, the delivery mode of SaaS enables providers to apply *software renting* (*subscription-based revenue model*), where customers buy the rights for software usage for a certain time period defined in the rental agreement (Choudhary, 2007; Ojala, 2012, 2013), or *usage-based pricing* (customers are charged based on the actual usage of the software).

In software *renting*, the ownership of the software is not transferred from the providers to the customers, and the software may be used without paying high initial fees or investing in IT infrastructure and professional IT personnel (Ojala, 2016a). Some studies on software renting investigate the benefits of software renting compared to traditional software licensing from both customers' and providers' perspectives (Choudhary, 2007; Choudhary, Tomak, & Chaturvedi, 1998a; Ojala, 2012, 2016a). One common benefit for both customers and providers is the possible cost savings for customers and the higher revenues for providers (Choudhary, 2007). In addition, Choudhary et al. (1998a) argue that customers may rent the software instead of buying in many cases, such as if the software is needed only for a short period, if the customer wants to experience or test the software, or if the customer wants to avoid negative network externalities, where an increase in the number of users decreases the value of the software. Thus, the decision about possible software renting depends both on service characteristics and the length of time the software is needed (Choudhary et al., 1998a; C. S. Tang & Deo, 2008). On the other hand, software providers may choose renting their software for many reasons. First, renting may decrease the providers' transaction costs related to searches and quality assurance (Choudhary, 2007) or software delivery (Varian, 2000). Renting may also increase the positive network effects through making the software more available due to its delivery mode (Choudhary et al., 1998b).

The emergence of cloud technologies enables using *usage-based pricing* (pay as you go, pay per use), similar to that of utilities. Applying this revenue model requires monitoring and measuring the usage, and it implies billing tasks, resulting in additional transaction costs for the providers (Armbrust et al., 2010; Gohad, Narendra, & Ramachandran, 2013; Lehmann & Buxmann, 2009). However, studies reveal that customers prefer using usage-independent assessment bases compared to usage-dependent variables (Lehmann & Buxmann, 2009) and that customers are willing to pay more for unlimited use (Sundararajan, 2004). Consequently, companies using usage-independent pricing models might achieve greater profit than by using usage-based pricing (Fishburn & Odlyzko, 1999). On the other hand, customers may over- and underestimate their usage, which results in bias regarding the benefits of usage-dependent and usage-independent pricing models (A. Lambrecht & Skiera, 2006). As a solution to this problem, usage-based pricing and software renting may be combined. In this terminology, pricing models consist of both usage-dependent pricing metrics (linked to the actual usage) and usage-independent pricing metrics (representing only the usage potential) (Lehmann & Buxmann, 2009; Lehmann et al., 2012). Using both usage-dependent and usage-independent pricing components may result in revenue increase for software providers compared with using a pricing model with only one component (Lehmann & Buxmann, 2009; Sundararajan, 2004).

Organizations often use *price discrimination* when the same product or service is offered to different customer segments at different prices (Choudhary, Ghose, Mukhopadhyay, & Rajan, 2005). This strategy is especially beneficial for software providers with low variable costs, since they may reach customer segments with a lower willingness to pay (Lehmann & Buxmann, 2009). In the literature, *versioning* (or tiered pricing) is also referred to (second degree) price discrimination, where the provider offers different product–price combinations to its customers (Varian, 1997). Even though providers may achieve revenue increase due to second degree price discrimination (Bhargava & Choudhary, 2001b), a number of versions that is too high may be confusing for customers and may increase variable costs for providers (Viswanathan & Anandalingam, 2005).

Pricing models might differ also in the *scope* of the offer that represents its granularity (Iveroth et al., 2013; Lehmann & Buxmann, 2009). In an offer, each unit can be priced separately, or in the case of *price bundling*, several items may be bound together with a predetermined price (Lehmann & Buxmann, 2009). Items in the bundle can be of various types, such as software products, IT services, and human services (also called a hybrid bundle; Veit et al., 2014). From the providers' perspective, the benefits of price bundling can vary. First, it may be used for price discrimination, especially when the willingness to pay is difficult to forecast separately for each unit (Viswanathan & Anandalingam, 2005). Then, bundling allows a greater distribution of different units that may cause an increase in revenues due to network externalities (Lehmann & Buxmann, 2009). Finally, cost savings may be achieved due to a decrease in transaction costs of billing and delivery (Viswanathan & Anandalingam, 2005).

In some cases, customers may be involved in the pricing process as well (Iveroth et al., 2013). Depending on the ability of buyers and sellers to *influence* the price, prices can be communicated through a *pricelist*; they may be the result of *negotiation* between the buyer and seller, or it may depend on some measurable *result* of the product or service (Iveroth et al., 2013). In an *auction*, prices are set based mostly on the customers' willingness to pay (Hinz, Hann, & Spann, 2011; W. Wang, Liang, & Li, 2013). Finally, *exogenous pricing* is used when the price depends on external circumstances beyond the customers' and providers' influence (Iveroth et al., 2013).

Providers may have different *pricing strategies* that may change the price dynamically over time (Lehmann & Buxmann, 2009). When using a *long-term real price* strategy, prices are not adjusted over time, only if necessary. When following the *penetration* strategy, the product or service is offered at a low price at the market entry phase and increased later. As a contrast, *skimming* means high prices in the market entry phase and a gradual price decrease later. Using these strategies can influence the demand behavior of price-sensitive customers (Liu, Cheng, Q. C. Tang, & Eryarsoy, 2011; Rohitratana & Altmann, 2012).

Several additional pricing strategies have been analyzed in the literature, such as *follow-the-free* (*freemium, free*; Cusumano, 2007), *complementary pricing* (Harmon et al., 2009), *premium pricing* (Harmon et al., 2009), *random or periodic discounting* (Harmon et al., 2009), *mixed pricing* (Hazledine, 2017), and so on. Many of these can be described through the pricing model elements presented above and represent a combination of different pricing models (i.e., they are hybrid pricing models). These pricing strategies may create both opportunities and challenges for providers and customers (Harmon et al., 2009). For example, in some cases, offering free services may be more beneficial for providers than charging customers (Jhang-Li & Chiang, 2015).

Aside from the pricing model, the cost structure of the cloud infrastructure also affects the companies' profits. The cloud infrastructure cost is described in the next subsection.

2.3.2 Cost factors in cloud infrastructure

The firm's cost structure measures all the costs incurred to create, market, and deliver value to the customers (Osterwalder, 2004). Cloud computing offers a significant reduction in IT infrastructure costs; however, the cost-efficiency of a cloud is determined by a multitude of cost factors that have a compound effect on the total costs.

In the cloud computing literature, different works of research study the cost determinants from different perspectives. A large body of research aims to provide a better understanding about the role that cost determinants have on the overall costs. The studies investigating different research issues are described in Table 1.

Table 1 Studies on cost structure of cloud infrastructure

Research issues	References
costs of a data center	Greenberg, Hamilton, Maltz, & Patel, 2008; Koomey, Brill, Turner, Stanley, & Taylor, 2007; Turner & Seader, 2006; Walterbusch, Martens, & Teuteberg, 2013
public cloud infrastructure	Kratzke, 2012; Mian et al., 2012; Truong & Dustdar, 2010
hybrid cloud infrastructure	Kashef & Altmann, 2012; Mazhelis, 2012; Mazhelis & Tyrväinen, 2011, 2012
cost–benefit analysis of private vs. public cloud adoption	Bibi, Katsaros, & Bozanis, 2012; Brumec & Vrček, 2013; Han, 2011; Khajeh-Hosseini et al., 2012, 2011; Klems, Nimis, & Tai, 2009; Mastroeni & Naldi, 2011; Mazhelis, Tyrväinen, Tan, & Hiltunen, 2012; Naldi & Mastroeni, 2016; Risch & Altmann, 2008; K. Sun & Li, 2013; Tak et al., 2011, 2013; Walker, Brisken, & Romney, 2010; Weinman, 2011
selection of appropriate public cloud provider	Andrikopoulos et al., 2013; Marston et al., 2011; Martens, Walterbusch, & Teuteberg, 2012
costs and benefits for trading storage for computation	Adams, Long, Miller, Pasupathy, & Storer, 2009
spreading the stored data over many providers	Abu-Libdeh, Princehouse, & Weatherspoon, 2010; Ruiz-Alvarez & Humphrey, 2011, 2012
finding the most cost-effective data placement and compression combination among multiple storage providers	Agarwala et al., 2011
insurance against cloud storage price increase	Mastroeni & Naldi, 2012

When decision makers decide upon possible data migration into a cloud, they may use different cost-based metrics. These metrics and the references where these metrics are investigated in more detail are summarized in Table 2.

Table 2 Cost-based metrics used for the cost-based investigation of different deployment options

Cost-based metric	References
net present value of money	Brumec & Vrček, 2013; Mastroeni & Naldi, 2011; Mazhelis, 2012; Naldi & Mastroeni, 2016; Tak et al., 2013; Walker et al., 2010
total cost of ownership	Bibi et al., 2012; Brumec & Vrček, 2013; Han, 2011; Klems et al., 2009; Koomey et al., 2007; Martens et al., 2012; Mazhelis et al., 2012; Walterbusch et al., 2013
value at risk	Mastroeni & Naldi, 2011; Naldi & Mastroeni, 2016
return on investment (ROI)	Beaty, Naik, & Perng, 2011; Misra & Mondal, 2011

Based on the studies mentioned above, the costs factors considered in the literature can be grouped into the following categories:

1. *Costs factors related to in-house resources*: These include the cost related to acquiring, provisioning, and maintaining a private data center during its whole lifecycle (e.g., hardware costs, software license fees, labor costs, cost of business premises, electricity costs, cost factors related to the strategy, and the practices of the organization, such as data center utilization rate, acquisition, and forecasting intervals).
2. *Costs factors related to public resources*: These include storage costs, computations costs, data communications costs, load balancing costs, pricing models of cloud providers, volume discounts, charging periods, market and technological trends, and so on.
3. *Cost factors related to the interaction between the private and public cloud and/or the use of a private and public cloud concurrently*: These include costs related to partitioning and resource allocation, data communication intensity between in-house and public resources, the threshold for workload reallocation between the private and external subsystems, and so on.
4. *Cost factors related to the organizational, environmental, or system context:* These include the system's or service's usage pattern, the demand growth rate, uncertainty, variability, system architecture, the type of the applications, the requirements for the applications, organization size, and so on.
5. *Other cost factors*: These include the cost factors related to the process of decision-making regarding possible cloud adoption, the selection of a cloud provider, the deployment cost, the integration cost, the migration cost, the configuration cost, the support and maintenance cost, the training cost, the potential losses due to cloud adoption, and so on.

The detailed list of the cost factors and the references where these cost factors are mentioned can be found in Appendix A.3 of Article V. Next, the cost-reduction approaches are analyzed in case of a cloud storage.

2.3.3 Cloud storage and cost-reduction approaches

The dramatic increase in data volume lately, and thus, the increasing storage costs and the emergence of cloud computing technologies, has caused organizations to rethink their data storage management strategies and find different cost reduction approaches to minimize the costs related to storing and managing their data (Mansouri & Buyya, 2016). The emergence of cloud technologies offer different storage solutions; however, organizations have to take into consideration the special characteristics and requirements related to their data, such as large volume, soft performance requirements, online accessibility, diverse data access patterns, data durability, data availability, data usability, access performance, security, and privacy; however, the low cost is a vital requirement aside from rich functionality (Agarwala et al., 2011; Palankar, Iamnitchi, Ripeanu, & Garfinkel, 2008);

Depending on the storage solution and the requirements, the cost of storage can be reduced using different techniques. One of these is the use of *data transformation*, such as data compression, data deduplication, and transcoding (Agarwala et al., 2011). Indeed, the use of different *data compression* algorithms reduces the volume of the data, however, it increases the memory and processing resource consumption and causes additional delays in restore operations (Agarwala et al., 2011; Mao, Jiang, Wu, Fu, & Tian, 2014). In addition, as utilized in cloud backup and archiving systems, as well as in virtual machine servers, the needed storage space can be also reduced via *data deduplication*, which is a type of data compression where each unique data chunk is stored only once (Clements, Ahmad, Vilayannur, Li, 2009; Mao et al., 2014; Rao, Reddy, & Yakoob, 2018). Finally, the use of *erasure codes*, such as Reed-Solomon codes, promises the redundancy of infrequently assessed data (cold data; André et al., 2014; Jiekak, Kermarrec, Le Scouarnec, Straub, & Van Kempen, 2013), whereas the high availability requirements of frequently accessed data (hot data) is ensured by different data *replication* mechanisms (André et al., 2014; Jiekak et al., 2013). Cost savings may also be achieved when data replication mechanisms are used in conjunction with various *energy-saving strategies* (Long, Zhao, & Chen, 2014) or by employing efficient *audit services* to ensure data integrity (Zhu & Jing Zhang, 2012).

Organizations may maximize their storage cost-efficiency by storing only the *provenance* data and by regenerating the rest when necessary (Adams et al., 2009; Borthakur, 2007). In this case, companies have to find the best trade-off between storage and computational costs, whereas the intermediate data are stored in cloud storage (Muniswamy-Reddy, Macko, & Seltzer, 2009; Muniswamy-Reddy & Seltzer, 2010; Yuan, Yang, Liu, & Chen, 2010, 2011; Yuan et al., 2010). Aside from trading storage for computing resources, additional issues may arise from the legal and security requirements, from the easiness of computing the stored data, and whether the replacement of exact result with an approximation is acceptable (Adams et al., 2009). However, cloud storage providers should incorporate the provenance services into cloud storage offerings (Muniswamy-Reddy & Seltzer, 2010).

In the next subchapter, the literature on concurrent sourcing and the hybrid cloud has been studied.

2.4 Concurrent sourcing and the hybrid cloud infrastructure as an instantiation of it

Concurrent sourcing refers to simultaneous use of market contracting and vertical integration; that is, producing and buying the same components concurrently (Mols, 2017). The phenomenon has been studied in the organization and strategic management literature through the lenses of different theories, such as transaction cost economics, resource-based theory, neoclassical economics, resource and capability view, agency theory, theories of multi-profit center firms, life cycle theory, marketing channels, options theory, and knowledge-based theory (Mols, 2010; Mols, Hansen, & Villadsen, 2012; Porcher, 2016). However, different studies refer to the phenomenon with different names, such as tapered integration (Porter, 1980), plural governance (Heide, 2003), plural sourcing (Jacobides & Billinger, 2006), partial integration (Jacobides & Billinger, 2006), rightsourcing (Tiwana & Kim, 2016), and concurrent sourcing (Heide et al., 2013; Mols, 2010; Parmigiani, 2007; Parmigiani & Mitchell, 2009). In this dissertation, the term concurrent sourcing will be used consistently.

Recent literature on concurrent sourcing has sought clarification on what the phenomenon actually represents and what is meant by the "same input" that is simultaneously produced and outsourced. In particular, Krzeminska et al. (Krzeminska et al., 2013) reconceptualize the concept of the "same" into several degrees of similarity. The authors define the inputs as being similar based on (1) the overlap in the scientific or technological basis, (2) the similarity of the production techniques and equipment, (3) the comparability of the costs of using different inputs, (4) the comparability of a consumer's perception of a product made, and (5) the quality of a product made with different inputs. It is further emphasized that different degrees of similarity are more important in different cases.

The hybrid cloud infrastructure in general, and the hybrid cloud storage in particular, fit Krzeminska et al.'s (2013) definition of the "same output": (1) the in-house and public resources may serve the same necessity in the company, (2) a hybrid solution uses resources from multiple sources to provide storage services, (3) the costs of using in-house and public infrastructure are comparable, (4) the use of a hybrid cloud is often hidden from the customers, and (5) in case the hybrid cloud offers the same quality of service as a pure cloud solution would, the customers' perception of the service is not different regarding a pure or hybrid cloud solution. The degree of similarity can also be assessed based on the substitutability of production inputs (Parmigiani, 2003). In the case of hybrid storage, the substitutability of private and public resources can be analyzed based on, for example, data sensitivity, availability, and performance requirements. Thus, the hybrid cloud storage can be studied as a special case of the concurrent sourcing phenomenon.

Different theoretical explanations and empirical results are available in concurrent sourcing literature about why some organizations both make and buy the same service or good. The use of concurrent sourcing is associated with, among others, performance ambiguity and technological volatility (Krzeminska et al., 2013), the information asymmetry between buyers and suppliers (Heide, 2003), performance uncertainty (Heide, 2003; Parmigiani, 2007), technological uncertainty and overlap in the buyer's and provider's expertise (Parmigiani, 2007), the complementarity of the buyer's and provider's knowledge and incentives (Parmigiani, 2007; Puranam et al., 2013; Tiwana & Kim, 2016), stronger bargaining power due to better monitoring (Heide et al., 2013), the absorptive capacity and open innovation (Cruz-Cázares, Bayona-Sáez, & García-Marco, 2013), unreliable suppliers (Freeman, Mittenthal, Keskin, & Melouk, 2017) and the possibility of gaining benefits of external sourcing (e.g., cost advantages, flexibility) without a loss of control (Heide, 2003).

In addition to the above-mentioned reasons for using concurrent sourcing, another explanation comes from the transactional cost economics and neoclassical economics. Namely, the use of the concurrent sourcing is often explained by its potential to reduce the firm's production costs in the face of the diseconomies of scale (B. M. Lambrecht, Pawlina, & Teixeira, 2016; Mols, 2010; Parmigiani, 2003; Puranam et al., 2013). The discussion in the literature usually refers to the volume uncertainty coupled with the high cost of excess capacity as one of the main reasons behind the diseconomies of scale (Adelman, 1949; Mols, 2010; Parmigiani, 2003; Puranam et al., 2013). In this context, *volume uncertainty* reflects the difficulty in forecasting the demand accurately; thus, it can be defined as the degree of (in)precision with which the volume is predicted (Parmigiani, 2003, 2007).

When the demand volume is fluctuating and it is difficult to forecast accurately, organizations deciding to also produce for the peak demand are subject to periods of excess capacity; that is, the periods when the in-house production facilities are underutilized or idle (Pindyck & Rubinfeld, 1995). The risk of the diseconomies of scale due to an unutilized excess capacity may be reduced by serving the high probability component of demand with in-house resources and by using external providers for the peak demand (Heide, 2003; Puranam et al., 2013). In other words, the use of both internal and external resources helps firms hedge against volume uncertainty risks (Parmigiani, 2003). It shall be mentioned that, still, the empirical results on whether the selection of concurrent sourcing is motivated by the presence of volume uncertainty are contradictory (Krzeminska et al., 2013; Parmigiani, 2003).

In cases when organizations decide to also produce for peak demand, another reason for the diseconomies of scale could be the *variability*, that is, the natural variation in the volume (e.g., seasonal fluctuations), that may be deterministic and accurately predictable (Puranam et al., 2013). It has to be noted that the variability aspect has not been explicitly considered yet in the literature. In this dissertation, the term *variation* in the demand volume is borrowed from Belle (2008) and refers to volume uncertainty and volume variability as the main possible reasons for the diseconomies of scale.

One of the fundamental questions both in state-of-the-art concurrent sourcing and cloud computing literature is the optimal mix of internal and external sourcing (Sako et al., 2013). Indeed, in hybrid cloud literature, the cost-optimal mix of in-house and external resources has been a crucial research area, with studies focusing on dynamic resource allocation (Altmann & Kashef, 2014; Shifrin et al., 2013; Trummer et al., 2010; W.-J. Wang et al., 2013) and proactive resource provisioning (Mazhelis & Tyrväinen, 2012; Weinman, 2012). On the other hand, in concurrent sourcing literature, multiple factors were found to affect the optimal mix, such as volume uncertainty, resource cospecialization, supplier selection, and the cost and benefits of producing in-house resources and buying from external parties (Puranam et al., 2013; Sako et al., 2013). However, a research gap related to volume uncertainty has to be investigated further (Sako et al., 2013).

Indeed, even though transaction cost economics predicts that the organizations facing volume uncertainty rely on internal rather than external capacity (Williamson, 1985), it only considers the choice between the use of internal or external resources, and thus it does not explain the phenomenon of concurrent sourcing (Mols, 2010; Sako et al., 2013). Other research gaps in concurrent sourcing include (1) understanding whether this governance mode should be studied as a midpoint along the continuum of make and buy or, alternatively, a discrete choice with its own costs and benefits (Parmigiani, 2003, 2007); (2) determining whether concurrent sourcing represents a stable solution, or, alternatively, a transitory choice that is used only while the organization moves between the make and buy governance modes (Parmigiani, 2007); and (3) the impact of concurrent sourcing on performance outcomes (Heide et al., 2013).

The concurrent sourcing literature has two limitations when seen through the lenses of hybrid cloud research. First, the concurrent sourcing literature may not completely explain the simultaneous use of private and public cloud infrastructure because it does not take into account some special characteristics of a hybrid cloud, such as the special requirements (e.g., related to quality of service, data availability, confidentiality, or legal requirements) that enforce some resources being kept local. Second, the optimal mix of private and public resources in concurrent sourcing literature are explained in the matter of market conditions and firm strategy, while the hybrid cloud literature focuses on other factors that have an impact of optimal dynamic resource allocation while taking into account different requirements and constraints.

Thus, in summary, the theoretical interpretations and the empirical findings of the concurrent sourcing literature can be used in explaining the popularity of hybrid cloud solutions. Furthermore, the research gaps (including the role of volume uncertainty and variability) in concurrent sourcing literature are also relevant in a hybrid cloud context. However, taking into account the specifics of hybrid cloud characteristics (such as the requirements of quality of service, data sensitivity, and special demand curves) can contribute to a deeper general understanding of the concurrent sourcing phenomenon.

Next, the open research issues are identified from the literature that this dissertation focuses on.

2.5 Summary: research gaps in literature on pricing models and cost reduction approaches in a cloud context

Despite the extant literature, several relevant open issues have been found that warrant further investigation. The research gaps that this dissertation focuses on are described next.

The first issue is related to the need for a clear and systematic pricing framework that takes into account the special characteristics of cloud services. Even though the study by Lehmann and Buxmann (2009) thoroughly describes the pricing parameters of the software industry, the framework may be difficult to overview and use in practice. On the other hand, the general pricing framework proposed by Iveroth et al. (2013) does not take into account the special characteristics of the cloud industry. Therefore, a framework is needed that may stand as a base for further research and that may also be used as a communication and planning tool by practitioners in order to find the proper pricing model and evaluate its alternatives, advantages, and disadvantages.

The second open issue is related to the interrelations between software architecture and its pricing. In contrast to traditional software products, where the revenue model of the software has been developed at the final stage of the product development process, the pricing of SaaS has to be considered during the early design phase (Kittlaus & Clough, 2009). Thus, the emerging complexity and variety of SaaS pricing models affects software development, including software design and technical architecture (Barbosa & Charão, 2012). Even though the interrelations between architectural and pricing characteristics are vital to understand, in the literature, there is a shortage of studies analyzing the relationship between software architecture and pricing.

The third open issue is related to pricing model changes due to adoption of cloud technologies. With the emergence of cloud computing technologies, the software industry evolves, and organizations need to respond to market dynamism (Ojala, 2016a). Business processes, network, and scope have to be redefined, and strategic changes in business models have to be implemented (Battleson et al., 2016; Luoma, 2013). Different studies in current literature focus on business model changes due to technological advances and market dynamism (described in Section 2.1.1), as well as software firms’ revenue logic and their products and services (described in Section 2.3.1). Some studies analyze the impact of cloud computing technologies on the business models of software vendors (e.g., Boillat & Legner, 2013; Luoma et al., 2012; Luoma & Nyberg, 2011); however, these studies do not focus on revenue models. In addition, the qualitative study by Ojala (2016a) describes how software providers adjust their revenue model and use software renting as a competitive strategy in the software market. However, despite its importance, there is a shortage of quantitative studies on how pricing models change due to adopting cloud computing technologies in software business.

Additionally, open research issues are found in the literature related to cost reduction approaches of cloud storage. First, as described above, the state-of-the-art research focuses on different aspects related to the cost of different cloud storage solutions and proposes different mechanisms to reduce infrastructure costs. However, there are a couple of open questions that require further investigation. Particularly, even though the cost is a vital factor affecting the decision about possible cloud adoption, little attention has been devoted to the role that individual cost factors have on the total cost. One of these cost factors is the acquisition interval whose role in the cost-efficient use of private vs. public storage capacity has not been investigated yet.

Finally, another research gap is found from the intersection of literature on concurrent sourcing and hybrid cloud infrastructure. Despite the growing body of literature on different cost reduction mechanisms for hybrid cloud solutions, the economic effect of the acquisition interval on the costs of hybrid cloud storage has not been analyzed yet. In addition to the related study on concurrent IT sourcing by Tiwana and Kim (2016), the paper by Mazhelis and Tyrväinen (2012) is the only study in which the hybrid cloud infrastructure is seen as a form of concurrent sourcing. Thus, there is a research gap in investigating the concurrent sourcing phenomenon in the context of cloud infrastructure, where the specific characteristics of the hybrid cloud can be taken into account. In addition, the concurrent sourcing literature offers limited analytical and empirical insights into the role of volume uncertainty in simultaneous use of internal and external resources (Sako et al., 2013), while the role of volume variability has not been studied before. Therefore, there is a need for analytical inquiry and empirical validation that focuses on the role of volume variation (volume uncertainty and variability) in the costs of hybrid cloud storage.

3 THE SCOPE OF THE RESEARCH AND RESEARCH METHODOLOGY

This chapter provides an overview of the research scope and the research approach and methodology.

3.1 The scope of the research and research objectives

This dissertation investigates the financial aspects of business models, and its main scope is to provide means to improve the financial performance of organizations through mitigating their storage infrastructure costs and increasing their revenues. The scope of the research is shown in Figure 1, where the articles included in the dissertation are labeled A1-A5. The dissertation tries to fill some of the research gaps found in the literature (described in subsection 2.5). That is, it concentrates on actors of cloud ecosystems, such as SaaS providers offering SaaS solutions to their customers and organizations that may choose to cope with their storage needs by storing their data partially or totally in the cloud.

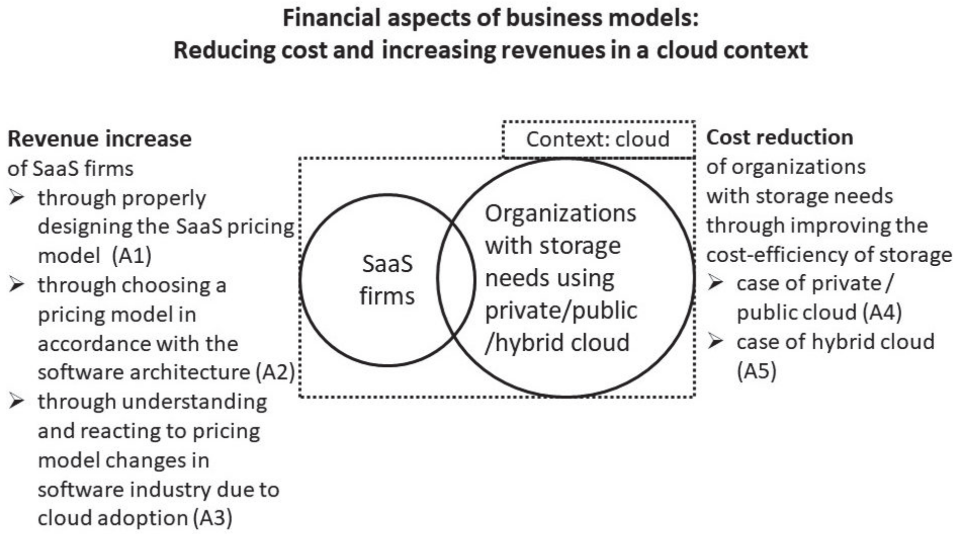


FIGURE 1 The scope of the research

First, the research considers SaaS firms and focuses on their revenue models. The research aims to support SaaS organizations to increase their revenues by designing suitable pricing models for their value propositions. In particular, the dissertation tries to achieve the following research objectives:

ro1. To identify the key elements of cloud services pricing models and to propose a cloud pricing framework that may be used as a base for further research and as a communication and design tool by practitioners responsible for pricing (addressed in Article I).

ro2. To investigate the relationship between SaaS architecture and pricing, in particular how pricing affects the software architecture and how the architecture of the software enables and limits its pricing (addressed in Article II).

ro3. To examine how software firms changed their pricing models due to adopting cloud computing technologies (addressed in Article III).

Next, the research considers organizations with great storage needs and focuses on cost-reduction approaches related to their storage infrastructure. The research aims to support companies' assessment of different sourcing options and fill the gaps in the literature by increasing understanding on the cost-efficiency of different deployment alternatives and by providing means for mitigating the cost of storage. In particular, the specific research objectives related to cloud storage costs are the following:

ro4. To investigate the role of acquisition interval on the cost-efficiency of private and public storage (addressed in Article IV).

ro5. To study the role of acquisition interval in concurrent sourcing through its impact on volume variation in the case of hybrid cloud storage (addressed in Article V).

It should be noted that even though different articles included in the dissertation address different research objectives, the results are combined in order to get a more holistic picture of the financial aspects of business models in a cloud context. Regarding the SaaS pricing, the outcome of Article I (i.e., the pricing framework) has been used in Articles II and III as a research base to investigate the relationship between software architecture and pricing qualitatively as well as to study the changes in pricing models due to cloud adoption quantitatively. Furthermore, regarding the storage costs, the impact of acquisition interval on the cost-efficiency of private and public cloud storage as well as on the total cost of hybrid cloud storage is analyzed in Articles IV and V.

3.2 Research approach

The IS research framework introduced by Hevner, March, Park, and Ram (2004) combines the behavioral and design science paradigms, where these two approaches complement each other. The behavioral research aims to find the truth and focuses on developing and justifying theories that explain or predict the phenomena under investigation. On the other hand, the goal of design science research (DSR) is utility, and this paradigm deals with building and evaluating artifacts (constructs, methods, models, or instantiations) that address specific issues (e.g., business needs; Hevner et al., 2004).

Answering different research questions requires the use of different research approaches and methods (Järvinen, 2001). In this dissertation, the solvable research problems are different in nature; therefore, both behavioral research and DSR is used. As a result, the contributions of studies using different approaches complement each other and extend the knowledge base of IS research.

Related to pricing, the aim of the research is to study the real world; therefore, the behavioral research approach is employed. First the conceptual-analytical research approach was used, where a theory, model, or framework is built using logical reasoning based on related theories, models, and frameworks from earlier studies (Järvinen, 2008; Swamidass, 1986). Using this approach, a cloud pricing framework was deductively inferred based on the literature using logical reasoning. The resulting framework is published in Article I and used in additional studies that study reality through both qualitative and quantitative research approaches (multi-case study in Article II and survey in Article III) in order to gain both an overview and deep insight into the topic.

Related to storage cost, the research subscribes to the DSR paradigm, where innovative artifacts are built and evaluated in the form of conceptual-analytical models, aiming to contribute to the creation of nascent theories on cloud storage costs (Gregor & Hevner, 2013). The research presented in Articles IV and V, respectively, consists of a single design and evaluation cycle. This cycle includes the build process, where an artifact is constructed in the form of a conceptual-analytical model and an evaluation process, where the built model is evaluated. During the evaluation phase, the model is analytically investigated to demonstrate the inherent regularities and then empirically tested in simulation studies that reflect real-life scenarios.

In the next subsections, the research approaches and methods are presented in detail: an empirical study for theory testing, a multi-case study, a survey, analytical mathematical research, and simulations.

3.3 Content analysis based on information collected from companies' web pages

Content analysis is a form of semiotics (Myers, 1997) describing a systematic and replicable method of compressing many words into fewer content categories using explicit coding rules (Markoff, Shapiro, & Weitman, 1975; Stemler, 2001); however, it can be defined more generally as any method applied to text or other symbols for the purpose of social science research (Duriau, Reger, & Pfarrer, 2007). Nowadays, one important data source for corporate information is a company's website, which can be used by researchers employing content analysis (Duriau et al., 2007). It should be noted that in content analysis, reliability and validity issues may arise due to the ambiguity of word meanings, categories, and coding rules (Weber, 1990).

In this research, in order to evaluate the applicability of the developed cloud pricing framework empirically and to gain insight into the usage of different cloud solution pricing models, an empirical study was carried out in which the pricing models of cloud offerings from more than fifty organizations were collected from the firms' web pages and studied using content analysis. The results of this study were published in Article I.

The analysis consisted of the following steps: (1) selection of organizations for the data sample; (2) identification of the IaaS, PaaS, and SaaS value propositions and their pricing information from the companies' home pages; (3) exclusion of the offerings providing a different type of service or due to inadequate pricing information; and (4) iterative evaluation of the proposed pricing framework. After looking for pricing data of value propositions from more than 160 cloud service providers, 73 pricing models were built from 54 organizations by using the proposed cloud pricing framework.

The data sample was identified through Cloud Computing Showplace, an internet portal enlisting more than 2050 cloud providers, categorized into IaaS, PaaS, and SaaS providers at the time of the research (autumn 2012). This online directory was chosen because it contained the most comprehensive collection of cloud providers compared to other directories (such as cloudservicemarket.info or www.saasdir.com) and the portal seemed to be up-to-date and well-maintained. At the time of writing this dissertation, the portal listed almost 3000 cloud companies, a fact that underlines that this was the right choice at the time of the research.

The data sample contained all registered IaaS and PaaS providers, as well as one SaaS provider, with relevant pricing data from each industry sector. To increase the reliability of the sample, additional validation steps were taken, and the non-cloud offerings were excluded. In addition, data were excluded that provided inadequate information to understand the pricing logic as a whole.

The data were analyzed through content analysis, where each pricing model was matched with a pricing framework pattern (a combination of the positions of the pricing model aspects along the dimensions in the proposed pricing framework). While defining the positions, the item describing the pricing characteristic most accurately was selected. The evaluation of the pricing framework was done in an iterative process using the following evaluation criteria: (1) each pricing model characteristic can be matched to a position of a dimension in the pricing framework and (2) a pricing pattern in the pricing framework describes pricing models sharing the same characteristics. If the evaluation criteria were not met, the pricing framework was refined to address the issues, and a new iteration was started. This continued until the pricing framework pattern was defined for all sample data and the evaluation criteria were met.

3.4 Qualitative research method: multi-case study

Qualitative research methods enable researchers to study complex phenomena in their social and cultural context (Myers, 1997). Among different qualitative methods, the case study is an empirical investigation of a phenomenon in its real-life environment, especially when the boundaries of the phenomenon and the context are unclear (Yin, 2009). Furthermore, in multiple case studies, the researchers study more than one case to understand the similarities and the differences between the cases by analyzing data within each case separately as well as across the cases, resulting in stronger and more reliable evidence (Gustafsson, 2017; Yin, 2009).

One of the research objectives of the dissertation is to understand the interrelations between software architecture and pricing. Thus, the goal here is an in-depth investigation of a complex phenomenon in a real-life context, where architectural and pricing decisions are made. For this purpose, the case study is a suitable research method rather than quantitative measurement because the study aims to understand the behavior of a firm (Bhattacherjee, 2012; Paré, 2004; Yin, 2009). Furthermore, to achieve a wider exploration of the research objective, the multi-case study research method was chosen and carried out. The results were published in Article II.

In Article II, the research setting consisted of five software firms. The selection of the cases was carried out with the following criteria: (1) the case organizations develop software for different industries; (2) the data sample includes both startups and relatively old companies; (3) the sample includes both traditional software product firms and SaaS providers; (4) the data sample includes SaaS of different cloud maturity levels; and (5) researchers have easy access to the required data, as recommended by Stake (1995).

The required information was gathered from multiple sources from each case organization. The data were initially collected through semi-structured interviews with multiple managers of the case firms (resulting in data from 27 interviews altogether). The interviewees consisted of vice presidents, chief executive officers, sales managers, architects, technical leads, and project managers. The interviews lasted about 60 minutes; they were all recorded and transcribed. Then, the complete transcripts were sent back to the interviewees for review. Some of them commented on the content, and other interviewees accepted the transcripts as they were. In addition to live meetings, additional information was gathered through e-mails and phone calls. Furthermore, secondary information was gathered about the cases from the home pages, brochures, and press releases of the companies.

In the study, content analysis (described in more detail in subsection 3.3) was chosen as the data analysis method. As advised by Miles and Huberman (1994), the content analysis consisted of three concurrent flows of activity: (1) data reduction, (2) data displays, and (3) conclusion-drawing or verification. In the data reduction phase, first, a detailed case history of each firm was developed to understand the causal links between the events, as advised by Pettigrew (1990). Then, unique patterns of each case related to different subtopics were extracted from the data based on the interviews and other materials collected from the case firms (using tables). In addition, critical factors related to the phenomena were identified based on checklists and event listings (Miles & Huberman, 1994). In the data display phase, the relevant information from the findings of the earlier phase was arranged into new tables. In the conclusion-drawing and verification stage, first, the most important aspects were identified from the viewpoint of this study. At this point, patterns, regularities, explanations, and causalities were observed. Then, the results were verified and discussed in order to avoid misunderstandings. Finally, in the last stage of the research, the manuscript was sent to the representatives of each case organization for review.

3.5 Quantitative research method: survey

Quantitative research methods refer to a group of methods in which a large amount of data are collected and analyzed using statistics (Creswell, 2002). Among these, by using the survey method, researchers use a list of questions (i.e., a survey) to collect the data through e-mail, phone, or software (Gable, 1994; Kaplan & Duchon, 1988). By analyzing a representative sample of the data, the survey approach aims to provide generalizable statements related to the studied phenomena; however, it only provides a "snapshot" of the situation at the time of the data collection, and the underlying meaning of the data may stay hidden (Gable, 1994).

One of the research objectives of this dissertation is to provide a view on the transformation of the software industry as a result of cloud technology adoption. Because the aim is to increase the general understanding of the phenomena under investigation, quantitative study was employed, and the results were published in Article III.

The data were collected as part of the annual Finnish software industry survey in 2013 that focused on all Finnish organizations providing software products or services to their customers. The data were gathered using letters and web-based forms with e-mail invitations, following a modified version of the tailored design (Dillman, 2000). The survey was addressed to key informants of 4878 software companies that were contacted five times. As a result, 379 complete and 121 partial responses were collected.

After the data collection, the data were filtered to comply with the goals of the study. In particular, embedded software providers and software resellers were excluded from the data sample because the main focus of the study was on SaaS companies. In addition, software firms younger than two years were excluded because the research aimed to determine the factors causing changes in the companies' pricing models. As a result, the data sample was reduced to 324 responses.

Before running the data analyses, various checks were employed. In particular, the significant Shapiro-Wilk's normality test indicated that the data sample was not normally distributed; thus, nonparametric statistics were chosen. Then, by using box plots, four outlier responses were identified and removed. In addition, the common method variance problem (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003) was checked by applying Harman's single-factor test; the results indicated that the method variance was not a problem. Furthermore, various concerns were thoroughly investigated related to the ordinal regression analyses, such as the choice of link function, the multicollinearity of the independent variables, and the proportional odds assumption. Finally, the common possible biases in the survey research method (e.g., problems related to sampling, coverage, non-response, and measurement; Dillman, 2000) were taken into consideration during the analysis. In particular, the survey questions were formulated with the help of both researchers and field practitioners to avoid measurement errors. Furthermore, already tested scales were used whenever possible.

During the data analyses, the hypotheses were tested by using nonparametric correlations and multivariate ordinal regression analyses. In particular, to reveal the associations between cloud computing technologies, changes in value proposition, and pricing model elements, nonparametric correlations were used. In addition, to assess the pricing model changes due to cloud technology adoption and changes in value proposition, ordinal regression analyses were carried out.

3.6 Analytical mathematical research

The purpose of analytical mathematical research is theory building by studying how models behave under different conditions (Wacker, 1998). The research method involves defining concepts and developing new mathematical relationships between them using formal logic. Other names for analytical mathematical research include operations research and management science.

One of the research objectives of this dissertation is to deepen the general understanding of the impact of individual cost factors on the cost-efficiency of public vs. private storage as well as on the total cost of hybrid storage and thus to contribute to development of nascent theories on cloud storage costs (Gregor & Hevner, 2013). To achieve this, the analytical mathematical research method was chosen. The research used the guidelines of Wacker (1998) for theory building. First, the variables were defined carefully based on definitions from the literature. Then, the research domain was limited by explicitly stating the assumptions used in the model. Next, the relationships between the concepts were identified mathematically and the model was built. In the next step, the conclusions were drawn from the model deductively and the conditions were explicitly stated where the theory holds true. Finally, the theory was empirically tested using simulations. In addition, illustrative examples were presented that showed the regularities of the model. The analytical mathematical research method was used and presented in Articles IV and V.

3.7 Simulations

Numerical simulation is a simulation type that relies on numerical methods to quantitatively represent the evolution of a physical system (Colombo & Rizzo, 2009). By analogy with laboratory experiments, these calculations with numerical models are referred to as numerical experiments (Bacour, Jacquemoud, Tourbier, Dechambre, & Frangi, 2002; Bowman, Sacks, & Chang, 1993; Winsberg, 2003). Each numerical experiment studies how a particular combination of input parameters affects the output parameter of interest, and the set of the experiments is designed so as to maximize the amount of relevant information from a limited number of simulation runs (Hunter, Hunter, & George, 1978).

In this dissertation, presented in Articles IV and V, simulation studies are used in order to empirically evaluate the regularities of the analytical models capturing the effect of different cost constituents on the cost-efficiency of private vs. public storage, as well as on the total hybrid costs. In order to resemble reality, the simulation needs to rely on real demand for storage experienced by a real-world organization, as well as on the real pricing for the private and public storage resources. Thus, in Article IV, the storage demand profile of the backup and archiving service was used that the Oxford University provided to its senior members, postgraduates, and staff members (Morris, 2011). The historical data describing the storage growth over the years 1996-2011 were provided by Oxford University Computing Services (OUCS) and were collected from the OUCS annual reports available on the OUCS website[2]. On the other hand, in Article V, the real storage demand archived in the archival system of the National Center for Atmospheric Research/University Corporation for Atmospheric Research (NCAR/UCAR) over the period 1986-2014 was used. These organizations were chosen for the studies for the following reasons: (1) both of them represent examples of real-world organizations that experience great storage growth (exponential increase by roughly 40-50% annually) and develop and maintain large-scale storage solutions; (2) the historical development of storage needs was observable thanks to long-term traces of storage infrastructure; and (3) in contrast to commercial organizations keeping their infrastructure details in secret, the traces of storage growth of these organizations were publicly available.

In both studies, the unit price of the public storage was estimated by consulting the price list of Amazon Web Services (AWS) by Amazon, which is one of the leading providers of public cloud infrastructure services (Leong, Toombs, Gill, Petri, & Haynes, 2014). In the case of private storage, the unit prices for newly designed storage solutions were estimated using the costs incurred by Backblaze (Nufire, 2011).

The simulations were carried out using MatLab software that helped in evaluating the analytical models and provided illustrative graphs showing the effect of different cost factors on the cost-efficiency of private vs. public storage, as well as on the total hybrid costs.

2 http://www.it.ox.ac.uk/about/reports

4 OVERVIEW OF THE ARTICLES

4.1 Article I: “Cloud Services Pricing Models”

Laatikainen, G., Ojala, A., & Mazhelis, O. (2013). Cloud services pricing models. In *International Conference of Software Business* (pp. 117–129). Springer, Berlin, Heidelberg.

Research objectives

This paper addresses the research gap related to the shortage of a systematic cloud pricing framework that works as a base for further research as well as supports practitioners in developing the most suitable pricing model for their cloud solution. The framework is developed deductively based on already existing pricing models in the literature (Iveroth et al., 2013; Lehmann & Buxmann, 2009) and it is evaluated and refined empirically using content analysis of the pricing model data found on the web pages of 54 cloud providers. In addition, the most popular and the most rarely used pricing models are revealed in this study.

Findings

In this paper, a strategic pricing framework was proposed for the cloud industry that helps to clarify the alternative pricing models in order to let companies differentiate by price. The framework consists of seven dimensions illustrated on a continuous scale that describe different aspects of the value proposition: scope (granularity of the offer), base (cost/competitor/performance/value-based pricing), influence (the ability of buyers and sellers to influence the price), formula (connection between price and volume), temporal rights (length of the time period when the user can use the offering), degree of discrimination (the same product may be offered to different customers at different prices), and dynamic pricing strategy (prices are not fixed, but the seller may change them dynamically over time).

Furthermore, based on the empirical study of 73 pricing models of 54 cloud firms, the findings suggest that the most popular pricing model is offered through a price list where different functionalities are bundled in different packages, and these packages, with different contents and prices, are offered to the customers via subscription while applying time-, quantity-, or quality-based discounts. Among the pricing models of cloud solutions, rarely used pricing characteristics are results-based pricing, pay-what-you-want, auction pricing, exogenous pricing, per-unit rate with a ceiling, and first-degree discrimination.

Connection to the objectives of the dissertation

This study seeks to fulfill research objective ro1. In this study, the key pricing aspects are identified in the cloud context and structured into a pricing framework. The resulting cloud pricing framework is used as a base in Articles II and III.

4.2 Article II: "SaaS architecture and pricing models"

Laatikainen, G., & Ojala, A. (2014). SaaS architecture and pricing models. In *2014 IEEE International Conference on Services Computing (SCC)* (pp. 597–604). IEEE.

Research objectives

This paper tries to fill the research gap in studying the interrelations between architectural and pricing characteristics of SaaS software that has not yet been considered in the literature. Indeed, the architecture of SaaS software might limit or enable different pricing models (consider, for example, Google's advertisement-financed pricing model), and conversely, pricing models might influence the requirements of software architecture (for example, when proper logging mechanisms are needed for usage-based pricing). Thus, as a result of a multi-case study of five companies, the study aims to answer the following research questions: (1) How does software architecture enable and limit pricing models? and (2) What is the impact of pricing on the software architecture?

Findings

Concerning the impact of architecture on the possible pricing models, the study accentuates the importance of proper software architecture design. In particular, the findings suggest that well-designed, flexible architecture enables various pricing models, but poorly designed architecture limits the pricing. Scalability and high level of modularity are found to be the most important characteristics that allow the use of different pricing models for the same software.

The decision about the use of public cloud services requires pricing model adjustments as well, whether changing to usage-based pricing models or, on the contrary, changing from usage-based pricing to a simpler pricing model. In some cases, software architecture limits the pricing possibilities. As an example, moving to SaaS architecture and multi-tenancy lowers the negotiation power of the customers.

Concerning the impact of pricing models on the architecture, the study found that decisions related to pricing should be made and communicated early enough in the software development life cycle because pricing may give special requirements to the software architecture, such as the use of public cloud providers' resources, scalability, high customizability, etc. In addition, changes in pricing model may result in the need for additional components, such as different infrastructure, automatic billing, or configuration tools.

Connection to the objectives of the dissertation

This study seeks to fulfill research objective ro2 and emphasizes the interrelations between software architecture and its pricing. The results of this qualitative study, together with the findings from Article III, give an overview of the transformations of the software industry due to adopting cloud computing technologies.

4.3 Article III: "Impact of cloud computing technologies on pricing models of software firms – Insights from Finland"

Laatikainen, G., & Luoma, E. (2014). Impact of cloud computing technologies on pricing models of software firms–Insights from Finland. In *International Conference of Software Business* (pp. 243–257). Springer, Cham.

Research objectives

This study addresses the research gap in understanding and empirically evaluating the changes in pricing models due to cloud technology adoption. Thus, the article analyzes survey data from 324 Finnish software companies with statistical methods to answer the following research questions: (1) how pricing models change due to adopting cloud computing technologies, such as virtualization, multi-tenancy, online delivery, and configurability; and (2) whether changes in pricing model elements are caused solely due to adopting cloud computing technologies or through changes in the value propositions of the companies.

Findings

The research found that using cloud computing technologies implies changes in different dimensions of the pricing models. In particular, the results suggest that multi-tenancy is the most influential factor, affecting 4 out of 5 dimensions, while virtualization, online delivery, and configurability are associated with changes in some of the pricing model characteristics. SaaS companies simplify their pricing model, use usage-based pricing, mitigate the customers' influence, and unify their pricing across customers. However, the study found that the length of the subscription period is not shortened. These changes in pricing models are implemented jointly with the standardization of the value proposition.

Connection to the objectives of the dissertation

This quantitative study seeks to fulfill research objective ro3, and the findings increase the understanding of how the use of cloud computing technologies impacts the pricing models of software companies. The results, together with findings of Article II, provide an overview of a transforming software industry, where organizations implement both technological and business model changes.

4.4 Article IV: "Role of Acquisition Intervals in Private and Public Cloud Storage Costs"

Laatikainen, G., Mazhelis, O., & Tyrväinen, P. (2014). Role of acquisition intervals in private and public cloud storage costs. *Decision Support Systems*, 57, 320–330.

Research objectives

The aim of this paper is to provide a better understanding of how individual cost factors affect the cost-efficiency of private vs. public storage and to support decision-makers in assessing the cost-related benefits and risks related to possible cloud adoption. In particular, the study investigates the effect of acquisition interval on the cost-efficiency of private and public storage solutions. That is, the paper introduces an analytical model comparing the cost of in-house and public storage solutions and then evaluates it through simulation using real-life data as encountered by a university backup and archiving service.

Findings

The study analytically showed that the length of acquisition interval (for private storage) as compared to the length of the charging period (for public storage) has an impact on the cost-benefit of on-demand storage provisioning. In particular, for the generally experienced exponential growth of storage demand, the use of in-house storage is likely to become more beneficial cost-wise as compared to the use of public cloud storage when the length of the acquisition interval shortens and approaches the charging period of the public storage. Thus, in case the storage demand grows exponentially, reestimating future needs and acquiring the necessary private infrastructure more often makes the private cloud more cost-effective compared to the public cloud.

The research also found that if the storage demand grows quickly and the private data transfer cost is based on the maximum traffic within the charging period, then these data transfer costs may make the in-house storage more expensive and hence, the public storage becomes more cost-effective, even for shorter acquisition intervals.

In addition, the paper illustrated that aside from the acquisition interval, other factors, such as the utility premium charged by the public storage provider, the level of needed storage redundancy, the estimation error, and the data transfers, have a compound effect on the cost efficiency of the private vs. public storage. In particular, a decline in the utility premium, an increase in the storage redundancy, or an increase in the estimation error shortens the maximum length of the acquisition interval that can be allowed for the in-house storage to be less expensive compared to the on-demand public storage.

Connection to the objectives of the dissertation

This study, using mathematical analysis and simulation, addresses research objective ro4 and, together with Article V, emphasizes the role of acquisition interval when assessing the possible cost benefits related to the alternatives of using private, public, or hybrid cloud storage. In particular, this study revealed that the shorter the acquisition interval, the more cost-efficient private storage is compared to public storage.

4.5 Article V: "Cost benefits of flexible hybrid cloud storage: Mitigating volume variation with shorter acquisition cycle"

Laatikainen, G., Mazhelis, O., & Tyrvainen, P. (2016). Cost benefits of flexible hybrid cloud storage: Mitigating volume variation with shorter acquisition cycle. *The Journal of Systems & Software*, 122, 180–201.

Research objectives

The aim of this article is to fill one of the research gaps found at the intersection of the hybrid cloud and concurrent sourcing literature. In particular, to date, there is limited analytical insight into the impact of individual cost factors on the cost-efficient mix of internal and external resources in the case of hybrid cloud storage. Thus, the paper introduces an analytical model for capturing the compound effect of the acquisition interval and the demand variation (volume uncertainty and variability) on the total cost of hybrid cloud storage. Its goal is to answer the research question of "How does the demand reassessment interval, through its effect on the volume variation that the organization experiences, impact the cost-efficient mix of internal and external sourcing in hybrid cloud storage?". The model is analytically investigated to demonstrate its inherent regularities, and it is empirically evaluated through simulation using the storage data encountered via the archival system of the National Center for Atmospheric Research/University Corporation for Atmospheric Research (NCAR/UCAR).

Findings

This study analytically revealed that re-estimating storage needs and acquiring additional private resources more often (i.e., refining the acquisition interval) reduces the total hybrid costs. Furthermore, the magnitude of the cost savings depends on both aspects of the volume variation: the volume uncertainty (non-determinism) and the volume variability (non-stationarity). More specifically, regarding the volume uncertainty, the study analytically proved that if refining the acquisition interval implies a reduction in the forecasting inaccuracy, then the cost benefit of the refinement further increases, and it decreases otherwise. Furthermore, regarding the volume variability, it was analytically proved that shortening the acquisition interval decreases the volume variability, and thus, the overall costs are reduced.

In addition to these findings, the study indicated that if the storage needs grow linearly within the acquisition interval, then the greatest cost benefits can be achieved when the acquisition interval is refined at the middle of the period; for example, the length of the acquisition interval is shortened to half, such as from one year to six months. On the other hand, if the demand grows exponentially within the acquisition interval, the cost benefits are the greatest when the acquisition interval is cut into two after the half point of the time period. Moreover, in the case of linearly growing demand, the greater the utility premium, the greater the cost benefits due to acquisition interval refinement.

Finally, the research study evaluated the model through simulating the costs of a real storage organization, and it revealed that if the organization can shorten its acquisition period from one year to six months, assuming no additional costs due to the reassessment, it would achieve a 15% cost saving.

Connection to the objectives of the dissertation

This article addresses research objective ro5 and provides new insights into the effects of the acquisition interval and volume variation on the total costs of hybrid cloud storage. In particular, the findings suggest that the shorter the acquisition interval, the less expensive the hybrid storage. The overall hybrid storage costs can be further reduced if refining the acquisition interval increases the forecasting accuracy. In addition to making contributions to the hybrid cloud literature, this study contributes to the concurrent sourcing literature by assessing the roles of volume uncertainty and volume variation in the cost-efficient mix of internal and external resources.

4.6 Contributions to joint articles

The author's contribution to the articles is as follows.

The author of this dissertation served as the main author of Articles I and II. In particular, in both studies, she was responsible for the research idea, literature review, carrying out the empirical studies and the writing process. For both articles, the co-authors improved the manuscripts with constructive comments, helped with structuring the articles and modified the content.

For Article III, the authors worked jointly in designing the survey questions, conducting the statistical analysis and writing the article. Mikko Rönkkö and Juhana Peltonen at Aalto University administered the data collection.

Articles IV and V are the results of the close collaboration of the authors. Gabriella Laatikainen and Oleksiy Mazhelis worked together in building up the analytical model, testing the model through simulations and writing the articles. Pasi Tyrväinen reviewed the articles, provided constructive comments and contributed to the manuscripts' content.

5 RESULTS AND CONTRIBUTIONS

In this section, first the results of the research are summarized and the contributions to the literature and to the practice are outlined. Finally, the limitations and further research ideas are presented.

5.1 Results

In this subsection, the findings of the dissertation are presented, first related to the cloud pricing models and then related to the costs of the cloud infrastructure.

5.1.1 Increasing revenues of SaaS companies

The research contributes to the cloud pricing literature and supports pricing decisions related to cloud services that help firms to differentiate themselves from their competitors and to improve their financial performance. In particular, the results of this research provide aid in finding the proper pricing model as well as in understanding how the emergence of cloud computing changed the value propositions (including software architecture) and pricing models of software businesses. In particular, the research

i. proposes a seven-dimensional model that systematically describes the various aspects of cloud pricing models that should be taken into account when planning, developing or speaking about revenue models of cloud services (see research objective ro1),
ii. investigates the relationship between the software architecture and pricing models (see research objective ro2) and
iii. explores the changes in the pricing models of SaaS companies after adopting cloud computing technologies, such as virtualization, multi-tenancy, online delivery and configurability (see research objective ro3).

Next, the results of these investigations are described. The findings are structured based on the research objectives.

The key elements of cloud service pricing models

The findings related to this research objective are published in Article I. That is, a seven-dimensional model is proposed as displayed in FIGURE 2. The proposed framework is an extended and customized version of the SBIFT model (Iveroth et al., 2012) developed for the cloud industry, which takes into consideration both general knowledge about pricing and specific cloud characteristics. The dimensions of the model are presented as follows.

The **scope** dimension refers to the granularity of the offer. On the left side of the slider, a package of products/services is priced (*pure bundling*); meanwhile, the other extreme category is called *unbundling*, referring to the situation where each unit of the offer is priced individually and where buyers can decide to buy them or not. Between these, two forms of customized bundling (i.e., customers can choose the components of the bundle, whereas the seller determines the price and scope of the package; Hitt & Chen, 2005) reside: *bundling where the amount of some items can be chosen from predefined options*, and *bundling where the amount of some items can be chosen freely*.

The **base** dimension refers to the information base that dominates the pricing decisions. *Cost-based pricing* is the most widely used pricing method (Shipley & Jobber, 2001), where the seller determines the price floor based on the cost of developing, producing, distributing and selling goods. Another pricing formation strategy involves setting the price level according to the *competitor's price* of a comparable product or service (Danziger, Israeli, & Bekerman, 2006). In *performance-based pricing*, the seller guarantees a certain performance level for a negotiated price and pays a penalty if this is not achieved (Becker, Borrisov, Deora, Rana, & Neumann, 2008; Bonnemeier et al., 2010). Using *value-based* (demand-based) pricing strategies, providers define their prices based on customers' perceived value (Bonnemeier et al., 2010; Harmon et al., 2009; Hinterhuber, 2004).

The **influence** dimension reflects buyers' and sellers' ability to influence the price. If the provider alone decides the price, this is usually communicated through a *pricelist*. If the price is set based on a *negotiation* between the customer and the provider, then the starting point is also a pricelist, but the buyer can influence the final price. The next option is *result-based pricing*, where the price is determined based on some observable result of the product/service. In an *auction*, the price is set based on the customers' willingness to pay, and the sellers' influence on the price is limited. *Exogenous pricing* is used if circumstances beyond the sellers' and buyers' influence determine the price.

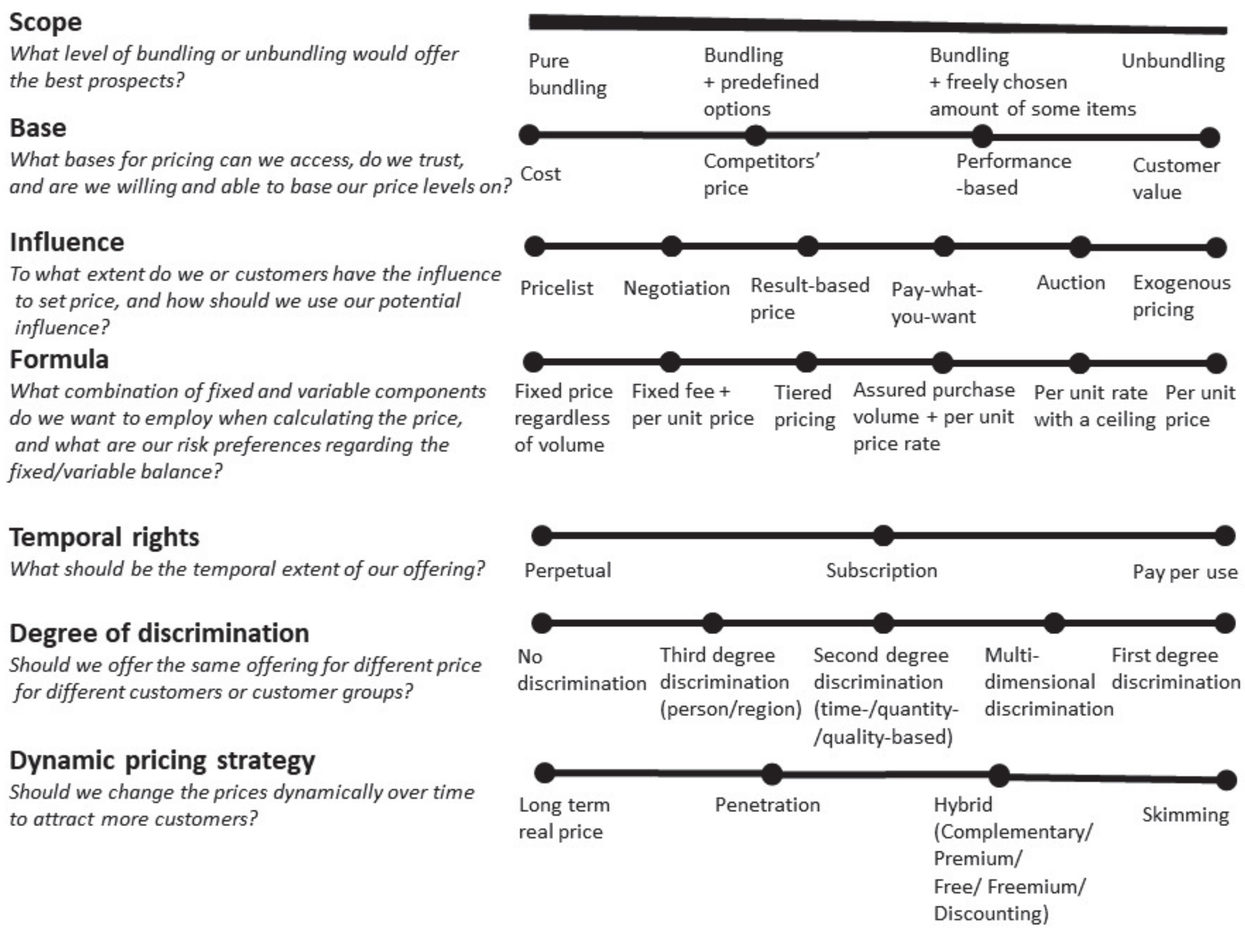


FIGURE 2 Cloud service pricing framework

The **formula** dimension refers to the connection between the price and volume. With a *fixed price regardless of volume* (flat pricing, eat-all-what-you-can), customers pay a fixed price that is independent from the used volume (Sundararajan, 2004). The *fixed fee plus per-unit rate* formula has two components: a fixed, predetermined, volume-independent part and a volume-dependent part. *Tiered pricing* refers to offerings with a fixed price and a limitation on the volume or the functionality, where the user has to switch to a less-limited offering with a different price if (s)he requests more volume or functionality. In the case of an *assured purchase volume plus per-unit rate*, a fixed volume amount is priced with a fixed price, and an overage price is charged for the extra consumption with the per-unit rate. Using the *per-unit rate with a ceiling* formula, the per-unit price has to be paid only until a certain consumption level, and above this, the usage is free of charge. In the case of *the per-unit price*, units (or units per time) are associated with fixed price values, and the customer pays this per-unit price regardless of the quality or economies of scale that the seller might encounter.

The **temporal rights** dimension refers to the length of time when the user can use the offering. In the case of a *perpetual* offering, the customer can use and own the goods as long as he or she wants to (Choudhary, 2007; Ferrante, 2006; Ojala, 2013). *Subscription* means offering customers the right to use the service/product for a fixed "rental" period during which they receive upgrades, enhancements, new functionalities or new content from the provider. If the buyers pay every time they use the service or product, the seller applies the *pay-per-use* (pay-as-you-go) mechanism.

The **degree of discrimination** refers to the level of price discrimination that is used when the same product/service is offered for various buyers for various prices. The left-most item, *no discrimination*, means the product/service is offered for the same price for everybody. In the case of *first-degree discrimination*, the vendor offers the same product/service at various prices for various customers. *Second-degree price discrimination* is used when providers sell various units of output at various prices (Spiegel, 1997; Varian, 1996). Second-degree price differentiations can be quantity, time and quality based (Lehmann & Buxmann, 2009; Varian, 1996, 1997). When applying *third-degree price discrimination*, the vendor identifies various customer groups based on their willingness to pay (Varian, 1997). Third-degree price discrimination can be personal (e.g., student discounts) or regional (e.g., various prices for developing countries) (Lehmann & Buxmann, 2009). *Multi-dimensional price discrimination* occurs when price differentiation is made based on more than one dimension (Lehmann & Buxmann, 2009).

The **dynamic pricing strategy** dimension refers to the strategy where prices are not fixed for relatively long periods. Rather, the seller dynamically changes the prices over time based on factors such as the time of sale, demand information and supply availability (Anandasivam, Buschek, & Buyya, 2009). With the *long-term real price* strategy, prices are kept the same for longer periods, and they are adjusted only if necessary, not as a part of a predetermined strategy. The *penetration strategy* refers to a strategy where vendors use low prices for faster market entry and then increase prices over time (Dean, 1969; Shipley & Jobber, 2001). In the case of *skimming*, the vendor sets high prices in the early stages of market development and then gradually reduces the prices to attract more price-sensitive market segments (Shipley & Jobber, 2001). *Hybrid pricing strategies* (Harmon et al., 2009) combine elements of penetration and skimming strategies and may contain the following, for example: *complementary pricing*, *premium pricing*, *free*, *freemium/follow-the-free* or *random or periodic discounting*.

The relationship between software architecture and pricing

The findings published in Article II revealed that the connection between the software architecture and pricing is especially tight when the cloud maturity level of the software is high, and when public cloud services are used for hosting. In these cases, the architecture impacts the pricing essentially, and additional pricing-related requirements arise. Nevertheless, the relationship between the architecture and pricing is more negligible in the case of startups or smaller companies where the focus is on software development.

A flexible, well-designed architecture is an enabler of alternative pricing models, whereas a poor architectural design restricts the pricing model possibilities. The most vital architectural characteristics related to pricing are scalability and the high level of modularity. Moreover, considering the use of public cloud services causes changes in the pricing models. In particular, using the cloud services of public providers may cause organizations to switch to usage-based pricing, or they just simplify the existing pricing model. Furthermore, implementing multi-tenancy mitigates the software's customizability; therefore, the customers' negotiation power decreases as well.

The effect of SaaS architectural characteristics on the pricing models is depicted in FIGURE 3. In the picture, solid arrows are used to show how different architectural characteristics *enable* different pricing aspects, whereas dashed arrows represent a *limiting* relationship between them. On the left side, different architectural characteristics are listed, whereas on the right side, some of the dimensions are presented from the cloud pricing model framework proposed in Article I.

The interrelations presented in the figure can be described as follows:

1. Using public cloud services affects the decision regarding subscription-based or usage-based pricing (temporal rights and formula dimensions).
2. Customizability has an impact on the influence that the customers have on the pricing model (influence dimension).
3. High service modularity enables various bundling alternatives (scope dimension).
4. Multi-tenancy limits the customizability that may restrict the customer's negotiation power (influence dimension).
5. A high level of multi-tenancy permits various options for the temporal rights dimension of the pricing model.

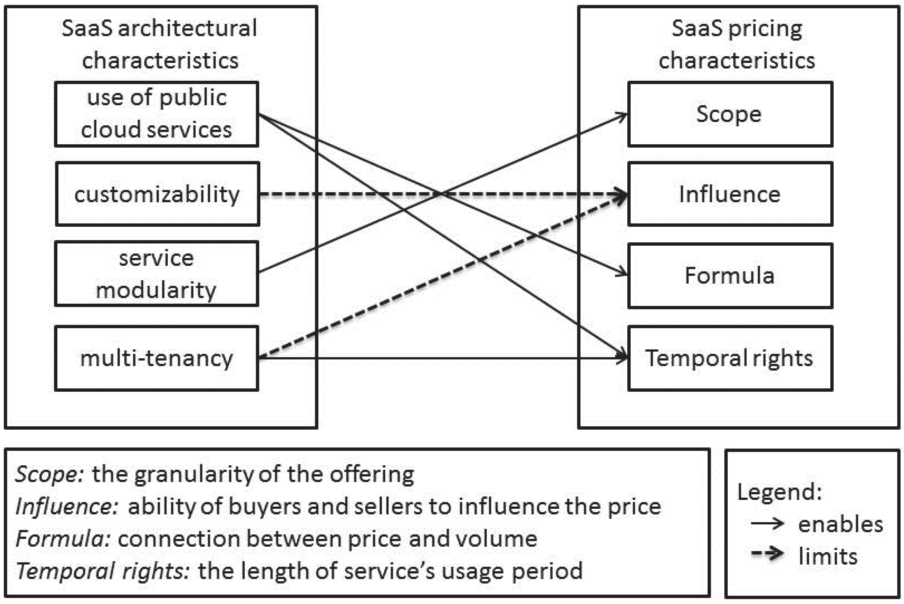


FIGURE 3 The impact of architecture on pricing models

The results of both studies published in Article II and III are in line with the literature (e.g., Guo et al., 2007), indicating that multi-tenancy is the most influential factor in inducing changes in pricing model elements, whereas other cloud technologies, such as virtualization, online delivery and configurability, are associated with changes in only some of the pricing model aspects.

Finally, the results of the study published in Article II emphasize that the decisions related to pricing should be made and communicated early enough in the software development life cycle. This is due to the architectural requirements that the pricing posits, such as scalability, high customizability and the use of public cloud providers' resources. Actually, this finding underlines Choudhary's finding: The use of subscription-based pricing model leads to higher architectural requirements, and this implies increased software quality (Choudhary, 2007). Moreover, the findings revealed that if the pricing model changes, additional components may be needed (e.g., various infrastructures, automatic billing and configuration tools). Finally, the results suggest that the pricing models impact the work prioritization as well.

Changes in pricing models due to adopting cloud computing technologies

For the purpose of describing how software companies changed their pricing models after making use of cloud technologies, the findings of the empirical, qualitative and quantitative studies presented in Articles I, II and III are combined.

Notwithstanding that the migration from on-premises solutions to cloud services usually requires great effort and investment, software companies see this choice as the only way in which to survive under heavy competition in the market (found in Article II). As a benefit of the adoption of cloud technologies, software companies standardize their value propositions (found in Article III) and implement changes to the pricing model elements related to various dimensions. In particular, firms using cloud computing technologies in their products and services simplify their pricing models (confirmed in studies Article II and III), take in use usage-based pricing (confirmed in the studies of Article II and III) and reduce customers' influence on pricing decisions (confirmed in the studies of Article II and III). In addition, they unify their pricing across customers and preferably offer a limited set of core functionalities (confirmed in the studies of Article I and III) with time-, quantity- or quality-based discounts (found in Article I). SaaS offerings are often communicated through pricelists (found in Article I). On the other hand, SaaS firms do not offer shorter contracts to their customers (found in Article III).

5.1.2 Reducing cloud storage costs

The research contributes to the literature on cloud storage as well as on concurrent sourcing, and it supports managerial decisions related to cloud storage that may lead to a reduction in the storage infrastructure cost. In particular, the research

i. explores the effect of the acquisition interval on the cost efficiency of private versus public cloud storage (see research objective ro4) and
ii. investigates the role of the acquisition interval as well as the volume variation (volume uncertainty and variability) on the total hybrid costs (see research objective ro5).

Concerning the cost efficiency of private versus public cloud storage, the results of this research support the decision regarding the possible use of public cloud services in organizations with growing storage needs by emphasizing the role of the acquisition interval on the cost of the private storage solution compared with the public one. The findings suggest that in the case of exponential storage growth, the use of public storage is expected to be more cost efficient in the case of relatively long acquisition periods compared with a pure in-house solution. On the other hand, if the company can re-estimate its storage needs and acquires additional storage resources often, then the private storage costs are likely to be lower compared with the cost of public cloud storage services. In addition, it was found that an increase in the storage redundancy, the estimation error or the data communication, or a decrease in the utility premium mitigates the maximum length of the acquisition interval that can be allowed for the private storage to be less expensive compared with the public storage.

On the other hand, related to the cost of the hybrid cloud, the research concluded that shortening the acquisition interval reduces the cost of hybrid cloud storage. Furthermore, if the forecasting inaccuracy decreases as a result of shortening the acquisition interval, then the economic benefit of reducing the length of the acquisition interval further increases, and it decreases otherwise. As an example, simulating the costs of a real organization with great storage needs revealed that if the organization shortens its acquisition cycle from one year to six months and additional costs do not emerge due to the reassessment, the magnitude of the cost saving would be 15% of the total storage costs.

In addition, related to the hybrid storage cost, the research also indicated that in cases where the storage needs to grow linearly within the acquisition interval, the greatest cost savings can be achieved when the acquisition period is divided into two equal halves (e.g., from one year to six months). However, in case the acquisition interval is long enough and the storage demand growth is exponential within the acquisition period, the cost savings are the greatest when the refinement happens after the half point of the time period. Moreover, in a case of linearly growing demand, the greater the utility premium, the greater the cost savings due to the refinement of the acquisition interval.

In summary, based on the results, it can be concluded that the role of the acquisition interval in the cost of the private or hybrid cloud storage solution is significant. The private storage infrastructure is likely to be more cost efficient when the acquisition intervals are short. On the other hand, the use of public cloud services is well justified cost wise in some cases, such as (i) in the cases of startup firms or small companies with insufficient resources and skills for building and managing their own infrastructures, (ii) in cases when storage needs are difficult to estimate or (iii) in cases where the organization's managerial practices do not facilitate the forecasting of future demand and the acquiring of additional in-house infrastructure resources frequently enough.

Besides the alternatives of the private and public cloud solutions, the hybrid cloud solutions provide cost-optimal solutions when the volume variation is high. That is, when the storage demand fluctuates, and/or when its volume is difficult to forecast, then the infrastructure cost can be reduced by serving the steady demand with private resources and by using public resources for the peak demand only. Moreover, the cost of the hybrid storage can be mitigated even more by refining the acquisition period of in-house resources as long as the cost of the refinement does not exceed the attainable cost benefit. On the other hand, the results suggest that the data communication between the private and public subsystems reduce the benefit of using the public cloud resources.

5.2 Contributions

The research provides insight into the financial aspects of organizations using cloud technologies. The research contributions are both theoretical and practical in nature. Concerning the theoretical contributions, the goal of the research was to extend the theoretical knowledge of pricing and cost models in the cloud context at various levels and to contribute to the literature on both cloud economics and concurrent sourcing. Regarding the practical implications, the research offers multiple ways of increasing companies' financial performance by increasing their revenues (in the case of SaaS firms) and reducing their infrastructure costs (in the case of companies with great storage needs). The research objectives, the key findings and the contributions are summarized in Table 3. The theoretical and managerial contributions are then described in more detail in the next subsections.

Table 3 Research objectives and summary of key findings and contribution

Research objective	Summary of key findings	Contribution
1. To identify the key elements of cloud service pricing models	The proposed cloud pricing framework describes pricing aspects along seven dimensions: scope, base, influence, formula, temporal rights, degree of discrimination and dynamic pricing strategy.	The framework may assist researchers and practitioners in identifying the key pricing model characteristics. The aim of this part of the research was to extend the theoretical knowledge at the analysis level (theory type I) (Gregor, 2006).
2. To investigate the relationship between SaaS architecture and pricing models	Flexible and well-designed software architecture enables a multitude of pricing models. Pricing may provide special requirements for the architecture.	The findings provided insights into the interrelations between the software architecture and pricing model. The aim of this part of the research was to extend the theoretical knowledge at the explanation level (theory type II) (Gregor, 2006).
3. To explain changes in the pricing models of software firms due to adoption of cloud technologies	Adopting cloud technologies implies changes in pricing models. In particular, SaaS firms simplify their pricing models, use usage-based pricing, mitigate the customers' influence, unify their pricing across customers, and standardize their value propositions at the same time.	This part of the research provided a view on the transforming software industry and had the goal of extending the theoretical knowledge at the explanation level (theory type II) (Gregor, 2006).
4. To study the role of the acquisition interval in the cost efficiency of the private and public storage	In the case of the generally experienced exponential growth of the demand for storage, the shorter the acquisition interval, the more cost efficient the private storage is compared with the public storage.	The research provided an analytical tool for supporting an organization's assessment of the cost efficiency of the private and public storage solution. The findings provided an increased understanding on the role of various cost factors, such as the acquisition interval, utility premium, data communication intensity, estimation error and redundancy level. This part of the research subscribed to the design science research paradigm with the goal of contributing to development of nascent theories on cloud storage costs (theory at the design and action levels, theory type V; Gregor, 2006; Gregor & Hevner, 2013).

5.	To study the role of the acquisition interval and volume uncertainty in concurrent sourcing in the case of the hybrid cloud storage	The overall hybrid storage costs can be reduced by re-estimating the storage needs and acquiring additional in-house resources more often. The extent of the cost benefits depends on both aspects of the volume variation: the volume uncertainty (non-determinism) and the volume variability (non-stationarity).	The research provided an analytical tool for estimating the total cost of the hybrid storage solution under the volume uncertainty. The findings contributed to the theoretical body of knowledge in both IS and the strategic management and operations management domain, as it deepens the understanding of the concurrent sourcing phenomenon in the context of the IS domain. It also provided new, analytical insights into the role of volume uncertainty in the concurrent sourcing. This part of the research subscribed to the design science research paradigm with the goal of contributing to development of nascent theories on cloud storage costs (theory at the design and action levels, theory type V; Gregor, 2006; Gregor & Hevner, 2013).

5.2.1 Theoretical contributions

Regarding implications for the literature, the results of this dissertation contribute to various research areas. First of all, the strategic pricing framework developed in this dissertation includes the conceptual basis for identifying the key characteristics of cloud service pricing models. This framework takes into consideration both the general knowledge about pricing and the specific cloud characteristics. Thus, it can be used in further research where the need exists to describe, develop or evaluate various cloud pricing models and their elements both systematically and clearly (e.g., the framework—proposed in Article I—is used in Article II and III). In addition, the research contributes to the literature by revealing the most popular and the most rarely used pricing models that cloud solution providers utilize.

Furthermore, the dissertation makes a contribution by accentuating the importance of the relationship between the architecture and pricing. Indeed, with the emergence of cloud computing technologies and various SaaS revenue models, architectural- and pricing-related decisions might affect each other. Thus, the findings regarding how various aspects of the SaaS architecture enable and limit the pricing (presented in FIGURE 3) can be used in further research. Furthermore, the results regarding the impact of pricing on the software architecture can be used in further research on software architecture and development processes.

Furthermore, the dissertation contributes to the literature by providing a view on the transforming software industry as well as the changes in software pricing models and value propositions due to cloud technology adoption. As a result of the adoption of cloud computing technologies, the market of software products and services evolves, and this dissertation provides a better understanding of these processes.

In addition to revenue logic, the research contributes to the cloud economics literature by increasing our understanding of (1) the cost efficiency of private versus public storage and (2) the cost-efficient mix of the internal and external resources of the hybrid storage infrastructure. The main contribution is the proposing of cost models that capture the compound effect of various cost factors on the storage cost. In particular, the research offers analytical tools designed (1) to support an organization's assessment of the cost efficiency of the private versus public storage solutions and (2) to estimate the total cost of the hybrid storage solution under the volume uncertainty and volume variability. Furthermore, the research underlines the role of the acquisition interval in the storage infrastructure costs. That is, the research offers tools for comparing the costs of various deployment options, taking into account the cost savings attainable through shortening the resource acquisition period.

Additionally, the research contributes to the IS literature by deepening our understanding of the concurrent sourcing phenomenon in the context of the IS domain. By studying concurrent sourcing through the lens of the hybrid cloud infrastructure, specific characteristics (e.g., non-decreasing storage needs, higher prices of external resources) can be taken into account as well. On the other hand, the results of this research contribute to the concurrent sourcing literature in the strategic management and operations management research domain. That is, the dissertation provides new, analytical insights into the role of volume uncertainty—a central concept in the concurrent sourcing literature—in the concurrent sourcing phenomenon. Furthermore, the research emphasizes and investigates the role of the variability aspect of the demand volume variation in the concurrent sourcing phenomenon, which, to the best knowledge of the author, has not been considered previously in the concurrent sourcing literature.

5.2.2 Practical contributions

The research has many managerial implications as well by providing means for increasing revenues and reducing costs for different stakeholders in the cloud ecosystem: SaaS providers and organizations with great storage needs. These implications vary in nature: Besides providing a better understanding of the software market, pricing models and infrastructure cost models, three tools have been developed to assist decision-makers in making more informed decisions.

Managerial implications for SaaS providers

Regarding SaaS providers, the research concentrated on their revenue models and provides new insights on the emerging new pricing aspects as well as on the changing software business market to help SaaS firms to obtain and preserve their positions among competitors in a constantly changing environment. In particular, the decision-makers at cloud provider companies can use the cloud pricing framework developed in this research as a tool for price modeling and communication. The tool helps with understanding and analyzing various pricing model alternatives and in this way allows for differentiation by price.

One practical implication of the research is an increased understanding of how SaaS providers are changing their value propositions and their revenue models, and thus, how the software market is evolving due to recent technological advances. SaaS firms have been found to standardize their services to reach additional customer segments, and consequently, they offer a restricted set of core functionalities through pricelists with time-, quantity- or quality-based discounts.

In addition, the research provides insights into (1) what technical details are important in decision-making about pricing, (2) what pricing aspects may have an impact on architectural decisions and (3) how particular cloud technologies affect various aspects of pricing. In particular, the research emphasizes the importance of a well-designed software architecture, where scalability, a high level of modularity and multi-tenancy are found to be the major enablers of a large variety of pricing models. On the other hand, pricing may provide special architectural requirements. Thus, designing and communicating the pricing model of the software is recommended in the early phase of the software development lifecycle, and communication between the software development and management departments is suggested to be continuous, as pricing models may have impacts on the software architecture, development and work prioritization.

In the qualitative study from this research, some companies found that adopting cloud technologies and transforming their traditional software products to SaaS offerings is the only way in which to remain competitive in the transforming software market. Indeed, the quantitative study using data from the Finnish software industry confirmed that the standardization of the value proposition happens together with changes in pricing models (such as simplifying the pricing model, implementing usage-based pricing, mitigating the customers' negotiation power, and unifying the pricing across customers). These changes happen in various aspects of the business model (including the value proposition and revenue model), and they may lead *together* to success. Thus, adopting cloud technologies in traditional software applications and changing their pricing models require great effort and investment; this must be planned carefully.

It has to be noted that the research did not reveal evidence that software companies are shortening their contracts with their customers due to the adoption of cloud technologies. This may be explained by the observation that even though cloud technologies enable the use of shorter contracts, software companies want to build long-term relationships with their customers to secure their incomes in the long term and to secure the returns on their initial investments.

Managerial implications for organizations with great storage needs

Regarding organizations with great storage needs, the managerial contributions of this research are related to the reduction of storage infrastructure costs. The research provides a detailed understanding of the various factors that constitute the cost of the storage infrastructure and it explores the various deployment alternatives from a financial point of view. That is, the research offers tools in the form of models for IT executives to assess the total costs of storage solutions with various deployment options. These models can be used to simulate the compound effect of various cost factors (such as the utility premium charged for public storage resources, the redundancy level, the error in estimating the demand needs and the volume of data transfers) on the cost efficiency of private versus public storage as well as on the total hybrid cost.

Undoubtedly, however, one of the key research findings is the possibility of reducing cloud infrastructure costs by reassessing the infrastructure needs and by acquiring additional in-house resources more often. That is, organizations may achieve financial benefits if they can change their internal practices and, if necessary, also shorten the supply time of additional in-house resources. Thereby, organizations are advised to consider the role of the acquisition interval when comparing in-house, public and hybrid storage solutions cost wise. Furthermore, the research provides additional information on the role of other factors on the cost-efficiency of private vs. public cloud. That is, the greater the level of redundancy, the greater the level of data communication, the less precise the storage demand estimation, the cheaper the unit price of the public storage provider, then the shorter the acquisition interval has to be for the in-house storage to be less expensive as compared with the public storage solution.

In real life, companies may deal with both easily predictable demand and varying data volumes that are difficult to forecast. In this research, both scenarios were analyzed. The findings suggest that when shortening the acquisition interval in case of hybrid cloud, if the demand estimation gets more precise, than the cost saving due to refining the acquisition interval increases; and it decreases otherwise. Refining the acquisition interval brings even more financial benefits when the utility premium charged by the public provider increases. In addition, using the analytical models, the magnitude of the cost savings attainable due to shortening the acquisition interval can be estimated and compared to the cost of re-estimating the storage needs more often. Additionally, based on the demand growth profile, managers receive hints on the time point when refining the acquisition period results in the greatest cost benefit. By feeding real data into the analytical models, the impact of various cost factors on the cost efficiency of the private and public solutions as well as on the total cost of the hybrid storage can be illustrated and compared. For example, the sensitivity analysis employed in the illustrative example using real-world data in Article IV indicated that the utility premium that the public cloud provider charges has a greater impact on the cost efficiency of the private and public solutions than the length of the acquisition interval does. Thus, in summary, this research supports decision-makers in evaluating various scenarios and deciding on the less costly solution.

5.3 Limitations and further studies

When evaluating the results, certain constraints and limitations have to be taken into consideration. First, the empirical research carried out in Article I was based on available data gathered online; therefore, the findings do not reflect the pricing models of organizations that do not display their pricing information on their website. Related to multi-case study in Article II, due to the methodological circumstances, the results cannot be fully generalized. Besides, the empirical data in Article III is gathered from software firms only in Finland, therefore the results cannot necessarily be read in a global context.

Regarding the investigations on the cost-efficiency of various cloud infrastructure solutions, it must be mentioned that the studies focused on storage resources only; therefore, the findings cannot be generalized to other raw infrastructure resources. In particular, the studies used the monotone increasing characteristic of storage growth function, namely that in contrast to the fluctuating demand for computing resources, the demand for storage often accumulates over time because newly created digital content only partially supersedes the already stored files.

The research presented in Articles IV and V focused on the cost factors affecting the decision regarding cloud adoption; however, when choosing between storage alternatives, IT executives consider several other factors besides cost, such as data availability, security, data confidentiality, privacy, elasticity, regulatory requirements, reliability, performance, integration with other services, personal preference and added value (Khajeh-Hosseini et al., 2012). Furthermore, the research took into consideration only a set of cost factors, such as storage needs and their growth and predictability, the storage acquisition interval, the costs incurred due to the transfer of data to and from the storage location, the unit price of an in-house solution, and the utility premium that the public cloud provider charges. However, additional factors may also affect storage costs, such as economies and diseconomies of scale, the cost of capital, the required levels of availability and durability, and the possibility of using data provenance. These and other factors do have a complex, non-linear effect on the overall costs, which makes them difficult to analyze (Mazhelis & Tyrväinen, 2012); therefore, including these factors in the analysis is important in future studies. It has to be noted that the findings related to storage costs cannot be fully generalized to other raw infrastructure resources (e.g. computing capacity) since as opposed to the storage needs, the demand for other resources does not increase continuously but rather fluctuates.

In further work, the research related to cloud pricing can be extended in several directions. First, the pricing processes of software companies should be investigated more thoroughly from the viewpoint of various theories in the IS research domain. Second, because the interaction between the actors of a business ecosystem has an impact on pricing as well, further studies are needed to develop an overview of how various actors' pricing models enable or limit one another's pricing models. Third, the impact of pricing on companies' internal processes should be explored in future studies.

Furthermore, the cost models in Articles IV and V can be extended in several ways. First, other factors affecting storage costs could be included in the analytical models as well. Second, the models could consider the declining pricing trends experienced lately. Third, in addition to deterministic storage growth profiles, probabilistic profiles could be investigated, too. Finally, the models could be reformulated as an optimization problem with the acquisition period as the decision variable.

YHTEENVETO (FINNISH SUMMARY)

Pilvipalveluiden liiketoimintamallien taloudellisia näkökohtia: kustannusten karsiminen ja liikevaihdon kasvattaminen

Organisaatioiden nykyään on sopeuduttava jatkuvasti uusiin teknologioihin ja olosuhteisiin selviytyäkseen markkinoiden voimakkaasta kilpailusta. Pilviteknologioiden ja vuokrattavien pilviresurssien nopea kehitys aiheuttaa muutoksia sekä ohjelmistotoimittajien että IT-infrastruktuuria käyttävien organisaatioiden liiketoimintamalleihin. Organisaatiot arvioivat julkisten, yksityisten ja hybridipilviratkaisujen käyttöä eri näkökulmista. Perinteisten ohjelmistotuotteiden sijaan ohjelmistoyritykset käyttävät tilaushinnoittelumallia ottaessaan käyttöön pilviteknologioita sekä tarjotessaan standardoidun palvelun netin kautta. Toisaalta organisaatioille, joiden varastointitarpeet kasvavat nopeasti, valitun tallennusratkaisun kustannukset ovat yksi keskeisistä päätöksentekoon vaikuttavista kriteereistä.

Väitöskirjassa käsitellään pilvipalveluiden liiketoimintamallien taloudellisia näkökohtia. Pilvipalveluiden hinnoittelumallien osalta tutkimuksen tulokset tarjoavat uusia havaintoja hinnoittelumallien eri elementeistä, ohjelmistoarkkitehtuurin ja hinnoittelumallien välisistä suhteista sekä pilviteknologian käyttöönoton vaikutuksista hinnoittelumalliin. Näitä havaintoja voidaan hyödyntää sekä tieteellisessä jatkotutkimuksessa että yritysmaailmassa. Esimerkiksi organisaatiot voivat parantaa tulostaan löytämällä palveluihinsa parhaiten sopivan hinnoittelumallin.

Pilvipalveluiden hinnoittelumallien lisäksi väitöskirja tarjoaa uusia näkemyksiä julkisten, yksityisten ja hybridivarastojen kustannustehokkuudesta. Tutkimuksen tulokset osoittivat analyyttisesti, että organisaatioiden varastointitarpeiden kasvaessa nopeasti yksityisen varastoinnin käyttö muodostuu kustannustehokkaammaksi organisaatioille lyhyellä hankintajaksolla, kunhan varastointitarpeita arvioidaan ja uusia tallennusresurssia hankitaan tarpeeksi usein. Toisaalta organisaatioille, joiden hankintajaksot ovat pidempiä, julkinen ratkaisu tulee todennäköisesti edullisemmaksi kuin yksityisen varastoinnin käyttö. Lisäksi hybridivarastoratkaisujen osalta tutkimuksessa todetaan, että hankintajakson lyhentäminen mahdollistaa hybridivarastoinnin yleiskustannusten pienentämisen. Tutkimus osoittaa myös, että jos hankintajaksoa lyhentämällä kysynnän volyymia voidaan ennustaa tarkemmin, silloin hybridivarastoratkaisujen kokonaiskustannukset pienenevät edelleen.

Väitöskirja sisältää monia eri tutkimustavoitteita, joten tutkimuksessa on käytetty useita erilaisia tutkimusmenetelmiä. Määrällisen ja laadullisen tutkimuksen sekä matemaattisen analyysin tulokset voidaan kuitenkin yhdistää. Näin ollen väitöskirja tarjoaa kokonaisvaltaisen näkemyksen pilvipalvelujen liiketoimintamallien taloudellisista näkökohdista.

ÖSSZEFOGLALÓ (HUNGARIAN SUMMARY)

A felhőszolgáltatások üzleti modelljeinek pénzügyi vetületei: költségcsökkentés és bevételnövelés

A jelenlegi kihívásokkal teli piaci versenyben a cégeknek folyamatosan alkalmazkodniuk kell az új technológiákhoz. A felhő technológiák és a bérelhető felhőerőforrások megjelenése az üzleti modellek megváltoztatására ösztökéli mind a szoftvergyártókat, mind pedig az informatikai infrastruktúrát használó vállalatokat. Egyrészt, a szoftvercégek a felhőalapú technológiák alkalmazása mellett megváltoztatják értékteremtési és bevételi modelljüket, és szoftver termékek helyett szabványosított szolgáltatásokat kínálnak előfizetéseken keresztül. Másrészt, azok a szervezetek, amelyeknek meg kell birkózniuk a gyorsan növekvő digitális tartalmak tárolási igényeivel, ki kell válasszák a számukra legmegfelelőbb tárolási megoldást, és a döntési kritériumok közül a tárolás költsége az egyik legfontosabb.

Ez a disszertáció különböző kérdéseket vizsgál a felhőszolgáltatások üzleti modelljeinek pénzügyi vonatkozásaihoz kapcsolódóan. Egyrészt, a felhőalapú szolgáltatások bevételi modelljeinek tekintetében új eredményeket szolgáltat az árazási modellek kulcsfontosságú elemeiről, a szoftver architektúra és az árazási modellek közötti kapcsolatról, valamint a felhőalapú technológiák alkalmazásából eredő változásokról a bevételi modellekben. A kutatás eredményei felhasználhatók nemcsak további kutatásokban, hanem a gyakorlatban is, hiszen segítséget nyújtanak a döntéshozóknak a megfelelő árképzési modell fejlesztésében.

Ezen kérdések vizsgálata mellett, az értekezés betekintést nyújt a publikus, privát és hibrid tárolási megoldások költséghatékonyságába. Egyrészt, a privát és publikus tárolási megoldás költséghatékonyságát illetően a kutatás analitikus módon kimutatta, hogy ha a tárolási igények gyorsan nőnek, a privát felhő használata valószínűleg költséghatékonyabb azon cégek számára, amelyek gyakrabban képesek újraértékelni a tárolási igényeiket, és beszerezni a privát tárolási infrastruktúra bővítéséhez szükséges eszközöket, azaz viszonylag rövid az ú.n. beszerzési ciklusuk. Ezzel ellentétben, a hosszabb beszerzési ciklussal rendelkező cégek számára a publikus tárolási megoldás olcsóbb a saját tárolási infrastruktúra létesítéséhez és fenntartásához képest. Másrészt, a hibrid infrastruktúra tekintetében a kutatás arra az eredményre jutott, hogy a hibrid tárolási költségek csökkennek amennyiben a cég beszerzési ciklusát lerövidítjük. Emellett a hibrid infrastruktúra összköltsége tovább csökken, ha az időintervallum lerövidítésével a tárolási igény jobban megjósolható.

Ez a kutatás a kutatási célok eltérő természetéből adódóan különböző kutatási módszertanokat alkalmazott. A kvantitatív, kvalitatív kutatások, az analitikus modellezés és a szimulációk eredményei összevonhatók, így holisztikusabb képet adhatnak a felhőalapú szolgáltatások üzleti modelljeinek pénzügyi vonatkozásairól.

REFERENCES

Abu-Libdeh, H., Princehouse, L., & Weatherspoon, H. (2010). RACS: a case for cloud storage diversity. In *Proceedings of the 1st ACM Symposium on Cloud Computing* (pp. 229–240). ACM.

Adams, I. F., Long, D. D., Miller, E. L., Pasupathy, S., & Storer, M. W. (2009). Maximizing efficiency by trading storage for computation. In *Proc. of the Workshop on Hot Topics in Cloud Computing*.

Adelman, M. A. (1949). The Large Firm and Its Suppliers. *The Review of Economics and Statistics*, *31*(2), 113–118.

Agarwala, S., Jadav, D., & Bathen, L. A. (2011). iCostale: Adaptive Cost Optimization for Storage Clouds. In *Cloud Computing (CLOUD), 2011 IEEE International Conference on* (pp. 436–443). IEEE.

Al-Debei, M. M., & Avison, D. (2010). Developing a unified framework of the business model concept. *European Journal of Information Systems*, *19*(3), 359–376. https://doi.org/10.1057/ejis.2010.21

Ali, A., Warren, D., & Mathiassen, L. (2017). Cloud-based business services innovation: A risk management model. *International Journal of Information Management*, *37*(6), 639–649. https://doi.org/10.1016/j.ijinfomgt.2017.05.008

Altmann, J., & Kashef, M. M. (2014). Cost model based service placement in federated hybrid clouds. *Future Generation Computer Systems*, *41*, 79–90.

Amit, R., & Zott, C. (2001). Value Creation in E-Business. *Strategic Management Journal*, *22*, 493–520.

Anandasivam, A., Buschek, S., & Buyya, R. (2009). A heuristic approach for capacity control in clouds. In *Commerce and Enterprise Computing, 2009. CEC'09. IEEE Conference on* (pp. 90–97). IEEE.

Anandasivam, A., & Premm, M. (2009). Bid price control and dynamic pricing in clouds. *ECIS 2009 Proceedings*. Retrieved from http://aisel.aisnet.org/ecis2009/284

André, F., Kermarrec, A.-M., Le Merrer, E., Le Scouarnec, N., Straub, G., & van Kempen, A. (2014). Archiving Cold Data in Warehouses with Clustered Network Coding. In *Proceedings of the Ninth European Conference on Computer Systems* (p. 21:1–21:14). Amsterdam, The Netherlands: ACM.

Andrikopoulos, V., Song, Z., & Leymann, F. (2013). Supporting the Migration of Applications to the Cloud through a Decision Support System. In *IEEE Sixth International Conference on Cloud Computing (CLOUD)* (pp. 565–572). IEEE.

Armbrust, M., Fox, A., Griffith, R., Joseph, A. D., Katz, R., Konswinski, A., … Zaharia, M. (2010). A View of Cloud Computing. *Communications of the ACM*, *53*(4).

Babcock, C. (2010). *Management Strategies for the Cloud Revolution: How Cloud Computing Is Transforming Business and Why You Can't Afford to Be Left Behind*. McGraw-Hill Education.

Bacour, C., Jacquemoud, S., Tourbier, Y., Dechambre, M., & Frangi, J.-P. (2002). Design and analysis of numerical experiments to compare four canopy reflectance models. *Remote Sensing of Environment*, *79*(1), 72–83.

Baden-Fuller, C., & Morgan, M. S. (2010). Business models as models. *Long Range Planning*, *43*(2), 156–171.

Banerjee, P., Friedrich, R., Bash, C., Goldsack, P., Huberman, B., Manley, J., … Veitch, A. (2011). Everything as a Service: Powering the New Information Economy. *Computer*, *44*(3), 36–43.

Barbosa, F. P., & Charão, A. S. (2012). Impact of pay-as-you-go Cloud Platforms on Software Pricing and Development: A Review and Case Study. In *Computational Science and Its Applications – ICCSA 2012* (pp. 404–417). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-31128-4_30

Battleson, D. A., West, B. C., Kim, J., Ramesh, B., & Robinson, P. S. (2016). Achieving dynamic capabilities with cloud computing: an empirical investigation. *European Journal of Information Systems*, *25*(3), 209–230. https://doi.org/10.1057/ejis.2015.12

Baur, A. W., Genova, A. C., Bühler, J., & Bick, M. (2014). Customer is King? A Framework to Shift from Cost- to Value-Based Pricing in Software as a Service: The Case of Business Intelligence Software. In *Digital Services and Information Intelligence* (pp. 1–13). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-45526-5_1

Beaty, K. ., Naik, V. K., & Perng, C.-S. (2011). Economics of cloud computing for enterprise IT. *IBM Journal of Research and Development*, *55*(6), 12:1-12:13. https://doi.org/10.1147/JRD.2011.2172254

Becker, M., Borrisov, N., Deora, V., Rana, O. F., & Neumann, D. (2008). Using k-Pricing for Penalty Calculation in Grid Market. In *Hawaii International Conference on System Sciences, Proceedings of the 41st Annual* (pp. 97–97).

Belle, G. van. (2008). *Statistical Rules of Thumb*. Wiley & Sons.

Benlian, A., & Hess, T. (2011). Opportunities and risks of software-as-a-service: Findings from a survey of IT executives. *Decision Support Systems*, *52*(1), 232–246. https://doi.org/10.1016/j.dss.2011.07.007

Bezemer, C., & Zaidman, A. (2010). Multi-tenant SaaS applications: maintenance dream or nightmare? In *Proceedings of the Joint ERCIM Workshop on Software Evolution (EVOL) and International Workshop on Principles of Software Evolution (IWPSE)* (pp. 88–92). Retrieved from http://dl.acm.org/citation.cfm?id=1862393

Bezemer, C., Zaidman, A., Platzbeecker, B., Hurkmans, T., & t Hart, A. (2010). Enabling multi-tenancy: An industrial experience report. In *Software Maintenance (ICSM), 2010 IEEE International Conference on* (pp. 1–8). Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5609735

Bharadwaj, A., El Sawy, O. A., Pavlou, P. A., & Venkatraman, N. (2013). Digital Business Strategy: Toward a Next Generation of Insights. *MIS Quarterly*, *37*(2), 471–482.

Bhargava, H. K., & Choudhary, V. (2001a). Information goods and vertical differentiation. *Journal of Management Information Systems*, *18*(2), 89–106.

Bhargava, H. K., & Choudhary, V. (2001b). Second-degree price discrimination for information goods under nonlinear utility functions. In *System Sciences, 2001. Proceedings of the 34th Annual Hawaii International Conference on* (p. 6–pp). IEEE.

Bhattacherjee, A. (2012). Social science research: principles, methods, and practices. Retrieved from http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1002&context=oa_textbooks

Bibi, S., Katsaros, D., & Bozanis, P. (2012). Business application acquisition: on-premise or SaaS-based solutions? *IEEE Software*, *29*(3), 86–93.

Bicer, T., Chiu, D., & Agrawal, G. (2012). Time and cost sensitive data-intensive computing on hybrid clouds. In *Proceedings of the 2012 12th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (ccgrid 2012)* (pp. 636–643). IEEE Computer Society.

Bittencourt, L. F., & Madeira, E. R. M. (2011). HCOC: a cost optimization algorithm for workflow scheduling in hybrid clouds. *Journal of Internet Services and Applications*, *2*(3), 207–227.

Bjorkqvist, M., Chen, L. Y., & Binder, W. (2012). Cost-driven service provisioning in hybrid clouds. In *5th IEEE International Conference on Service-Oriented Computing and Applications (SOCA)* (pp. 1–8). IEEE.

Böhm, M., Koleva, G., Leimeister, S., Riedl, C., & Krcmar, H. (2010). Towards a generic value network for cloud computing. *Economics of Grids, Clouds, Systems, and Services*, 129–140.

Boillat, T., & Legner, C. (2013). From On-Premise Software to Cloud Services: The Impact of Cloud Computing on Enterprise Software Vendors' Business Models. *Journal of Theoretical and Applied Electronic Commerce Research*, *8*(3), 39–58. https://doi.org/10.4067/S0718-18762013000300004

Bonnemeier, S., Burianek, F., & Reichwald, R. (2010). Revenue models for integrated customer solutions: Concept and organizational implementation. *Journal of Revenue & Pricing Management*, *9*(3), 228–238.

Bontis, N., & Chung, H. (2000). The evolution of software pricing: from box licenses to application service provider models. *Internet Research*, *10*(3), 246–255. https://doi.org/10.1108/10662240010331993

Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. *Journal of Cleaner Production*, *45*(Supplement C), 9–19. https://doi.org/10.1016/j.jclepro.2012.07.007

Borthakur, D. (2007). *The hadoop distributed file system: Architecture and design*. http://hadoop.apache.org/docs/r1.2.1/hdfs_design.pdf: The Apache Software Foundation.

Bowman, K. P., Sacks, J., & Chang, Y.-F. (1993). Design and analysis of numerical experiments. *Journal of the Atmospheric Sciences*, *50*(9), 1267–1278.

Brumec, S., & Vrček, N. (2013). Cost effectiveness of commercial computing clouds. *Information Systems*, *38*(4), 495–508.

Cai, H., Wang, N., & Zhou, M. J. (2010). A transparent approach of enabling SaaS multi-tenancy in the cloud. In *Proceedings of the 2010 6th World Congress on Services* (pp. 40–47). IEEE Computer Society.

Calheiros, R. N., Ranjan, R., Beloglazov, A., De Rose, C. A., & Buyya, R. (2011). CloudSim: a toolkit for modeling and simulation of cloud computing environments and evaluation of resource provisioning algorithms. *Software: Practice and Experience*, *41*(1), 23–50.

Casadesus-Masanell, R., & Ricart, J. E. (2010). From strategy to business models and onto tactics. *Long Range Planning*, *43*(2), 195–215.

Cavalcante, S., Kesting, P., & Ulhøi, J. (2011). Business model dynamics and innovation: (re)establishing the missing linkages. *Management Decision*, *49*(8), 1327–1342.

Cerviño, J., Rodríguez, P., Trajkovska, I., Escribano, F., & Salvachúa, J. (2013). A Cost-Effective Methodology Applied to Videoconference Services over Hybrid Clouds. *Mobile Networks and Applications*, *18*(1), 103–109.

Charrada, F. B., Tebourski, N., Tata, S., & Moalla, S. (2012). Approximate placement of service-based applications in hybrid Clouds. In *IEEE 21st International Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE)* (pp. 161–166). IEEE.

Chesbrough, H. (2007). Business model innovation: it's not just about technology anymore. *Strategy and Leadership*, *35*(6), 12–17.

Chesbrough, H., & Rosenbloom, R. S. (2002). The role of the business model in capturing value from innovation: evidence from Xerox Corporation's technology spin-off companies. *Industrial and Corporate Change*, *11*(3), 529–555.

Choi, S.-Y., Stahl, D. O., & Whinston, A. B. (1997). *The economics of electronic commerce*. Macmillan Technical Publishing Indianapolis, IN. Retrieved from https://xa.yimg.com/kq/groups/18990524/365094551/name/andrew_whinston-economics_of_electronic_commerce.pdf

Chong, F., & Carraro, G. (2006). Architecture strategies for catching the long tail. *MSDN Library, Microsoft Corporation*, 9–10.

Chopra, N., & Singh, S. (2013a). Deadline and cost based workflow scheduling in hybrid cloud. In *2013 International Conference on Advances in Computing, Communications and Informatics (ICACCI)* (pp. 840–846). IEEE.

Chopra, N., & Singh, S. (2013b). HEFT based workflow scheduling algorithm for cost optimization within deadline in hybrid clouds. In *Fourth International Conference on Computing, Communications and Networking Technologies (ICCCNT)* (pp. 1–6). https://doi.org/10.1109/ICCCNT.2013.6726627

Choudhary, V. (2007). Comparison of software quality under perpetual licensing and software as a service. *Journal of Management Information Systems*, *24*(2), 141–165.

Choudhary, V., Ghose, A., Mukhopadhyay, T., & Rajan, U. (2005). Personalized pricing and quality differentiation. *Management Science*, *51*(7), 1120–1130.

Choudhary, V., Tomak, K., & Chaturvedi, A. (1998a). Economic Benefits of Renting Software. *Journal of Organizational Computing and Electronic Commerce*, *8*(4), 277–305. https://doi.org/10.1207/s15327744joce0804_2

Choudhary, V., Tomak, K., & Chaturvedi, A. (1998b). Effect of network externalities on software pricing. In *System Sciences, 1998., Proceedings of the Thirty-First Hawaii International Conference on* (Vol. 4, pp. 251–260 vol.4).

Choudhary, V., & Vithayathil, J. (2013). The Impact of Cloud Computing: Should the IT Department Be Organized as a Cost Center or a Profit Center? *Journal of Management Information Systems*, *30*(2), 67–100. https://doi.org/10.2753/MIS0742-1222300203

Clements, A. T., Ahmad, I., Vilayannur, M., Li, J. (2009). Decentralized Deduplication in SAN Cluster File Systems. In *USENIX Annual Technical Conference* (pp. 101–114).

Colombo, S. P., & Rizzo, C. L. (2009). *Numerical Simulation Research Progress*. Nova Science Publishers.

Columbus, L. (2015). Roundup Of Cloud Computing Forecasts And Market Estimates Q3 Update, 2015. Retrieved 6 October 2015, from http://www.forbes.com/sites/louiscolumbus/2015/09/27/roundup-of-cloud-computing-forecasts-and-market-estimates-q3-update-2015/

Creswell, J. (2002). *Research design: Qualitative, quantitative, and mixed method approaches*. Sage Publications.

Cruz-Cázares, C., Bayona-Sáez, C., & García-Marco, T. (2013). Make, buy or both? R&D strategy selection. *Journal of Engineering and Technology Management*, *30*(3), 227–245.

Currie, W. (2004). Value creation from the application service provider e-business model: the experience of four firms. *Journal of Enterprise Information Management*, *17*(2), 117–130.

Cusumano, M. A. (2007). The changing labyrinth of software pricing. *Communications of the ACM*, *50*(7), 19–22.

Cusumano, M. A. (2008). The Changing Software Business: Moving from Products to Services. *Computer*, *41*(1), 20–27.

Cusumano, M. A. (2010). Cloud computing and SaaS as new computing platforms. *Communications of the ACM*, *53*(4), 27–29.

Danziger, S., Israeli, A., & Bekerman, M. (2006). The relative role of strategic assets in determining customer perceptions of hotel room price. *International Journal of Hospitality Management*, *25*(1), 129–145.

Dean, J. (1969). Pricing pioneering products. *The Journal of Industrial Economics*, 165–179.

Demil, B., & Lecocq, X. (2010). Business Model Evolution: In Search of Dynamic Consistency. *Long Range Planning*, *43*, 227–246.

Desai, B., & Currie, W. (2003). Application Service Providers: A model in Evolution (pp. 174–180). Presented at the ICEC.

Desair, T., Joosen, W., Lagaisse, B., Rafique, A., & Walraven, S. (2013). Policy-driven middleware for heterogeneous, hybrid cloud platforms. In *Proceedings of the 12th International Workshop on Adaptive and Reflective Middleware* (p. 2). ACM.

Dillman, D. A. (2000). *Mail and internet surveys: The tailored design method* (Vol. 2). Wiley New York. Retrieved from http://umaine.edu/ipm/files/2010/10/ME-PomologicalSociety-IPMawardNomination.doc

Dillon, T., Wu, C., & Chang, E. (2010). Cloud computing: issues and challenges. In *24th IEEE International Conference on Advanced Information Networking and Applications (AINA)* (pp. 27–33). IEEE.

D'souza, A., Kabbedijk, J., Seo, D., Jansen, S., & Brinkkemper, S. (2012). Software-As-A-Service: Implications For Business And Technology In Product Software Companies. Retrieved from http://aisel.aisnet.org/pacis2012/140/

Duriau, V. J., Reger, R. K., & Pfarrer, M. D. (2007). A content analysis of the content analysis literature in organization studies: Research themes, data sources, and methodological refinements. *Organizational Research Methods*, *10*(1), 5–34.

Durkee, D. (2010). Why Cloud Computing Will Never Be Free. *Queue*, *8*(4), 20:20–20:29. https://doi.org/10.1145/1755884.1772130

Dutta, S., Zbaracki, M. J., & Bergen, M. (2003). Pricing process as a capability: a resource□based perspective. *Strategic Management Journal*, *24*(7), 615–630. https://doi.org/10.1002/smj.323

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

Fadel, A. S., & Fayoumi, A. G. (2013). Cloud Resource Provisioning and Bursting Approaches. In *14th ACIS International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD)* (pp. 59–64). IEEE.

Fan, C.-T., Wang, W.-J., & Chang, Y.-S. (2011). Agent-Based Service Migration Framework in Hybrid Cloud. In *13th International Conference on High Performance Computing and Communications (HPCC)* (pp. 887–892). IEEE.

Ferrante, D. (2006). Software Licensing Models: What's Out There? *IT Professional*, *8*(6), 24–29.

Fishburn, P. C., & Odlyzko, A. M. (1999). Competitive pricing of information goods: Subscription pricing versus pay-per-use. *Economic Theory*, *13*(2), 447–470. https://doi.org/10.1007/s001990050264

Foster, I., Zhao, Y., Raicu, I., & Lu, S. (2008). Cloud computing and grid computing 360-degree compared. In *Grid Computing Environments Workshop, 2008. GCE'08* (pp. 1–10). Ieee. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4738445

Freeman, N., Mittenthal, J., Keskin, B., & Melouk, S. (2017). *Sourcing strategies for a capacitated firm subject to supply and demand uncertainty*. Article in Press. https://doi.org/10.1016/j.omega.2017.06.004

Freytag, P. V., & Kirk, L. (2003). Continuous strategic sourcing. *Journal of Purchasing and Supply Management*, *9*(3), 135–150.

Gable, G. G. (1994). Integrating case study and survey research methods: an example in information systems. *European Journal of Information Systems*, *3*(2), 112–126.

George, G., & Bock, A. (2011). The Business Model in Practice and its Implications for Entrepreneurship Research. *Entrepreneurship Theory and Practice*, *35*(1), 83–111.

Gohad, A., Narendra, N. C., & Ramachandran, P. (2013). Cloud Pricing Models: A Survey and Position Paper. In *2013 IEEE International Conference on Cloud Computing in Emerging Markets (CCEM)* (pp. 1–8). https://doi.org/10.1109/CCEM.2013.6684430

Greenberg, A., Hamilton, J., Maltz, D. A., & Patel, P. (2008). The cost of a cloud: research problems in data center networks. *SIGCOMM Comput. Commun. Rev.*, *39*(1), 68–73.

Gregor, S. (2006). The Nature of Theory in Information Systems. *Management Information Systems Quarterly*, *30*(3). Retrieved from https://aisel.aisnet.org/misq/vol30/iss3/5

Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly*, *37*(2), 337–356.

Gregory, R. W., Beck, R., & Keil, M. (2013). Control Balancing in Information Systems Development Offshoring Projects. *MIS Quarterly*, *37*(4), 1211–1232.

Greschler, D., & Mangan, T. (2002). Networking lessons in delivering ?Software as a Service??part I. *International Journal of Network Management*, *12*(5), 317–321. https://doi.org/10.1002/nem.446

Grönroos, C. (2011). A service perspective on business relationships: The value creation, interaction and marketing interface. *Industrial Marketing Management*, *40*(2), 240–247. https://doi.org/10.1016/j.indmarman.2010.06.036

Guo, C. J., Sun, W., Huang, Y., Wang, Z. H., & Gao, B. (2007). A framework for native multi-tenancy application development and management. In *E-Commerce Technology and the 4th IEEE International Conference on Enterprise Computing, E-Commerce, and E-Services, 2007. CEC/EEE 2007. The 9th IEEE International Conference on* (pp. 551–558). Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4285271

Guo, Z., & Ma, D. (2018). A model of competition between perpetual software and software as a service. *MIS Quarterly*, 1–46. https://doi.org/10.25300/MISQ/2018/13640

Gustafsson, J. (2017). *Single case studies vs. multiple case studies: A comparative study*.

Gutierrez-Garcia, J. O., & Sim, K. M. (2015). Agent-based Cloud bag-of-tasks execution. *Journal of Systems and Software*, *104*, 17–31. http://dx.doi.org/10.1016/j.jss.2015.02.039

Haile, N., & Altmann, J. (2016). Value creation in software service platforms. *Future Generation Computer Systems*, *55*(Supplement C), 495–509. https://doi.org/10.1016/j.future.2015.09.029

Hajjat, M., Sun, X., Sung, Y.-W. E., Maltz, D., Rao, S., Sripanidkulchai, K., & Tawarmalani, M. (2010). Cloudward bound: planning for beneficial migration of enterprise applications to the cloud. *ACM SIGCOMM Computer Communication Review*, *40*(4), 243–254.

Hallberg, N. L. (2017). The micro-foundations of pricing strategy in industrial markets: A case study in the European packaging industry. *Journal of Business Research*, *76*(Supplement C), 179–188. https://doi.org/10.1016/j.jbusres.2017.01.001

Han, Y. (2011). Cloud computing: case studies and total cost of ownership. *Information Technology and Libraries*, *30*(4), 198–206.

Harmon, R., Demirkan, H., Hefley, B., & Auseklis, N. (2009). Pricing Strategies for Information Technology Services: A Value-Based Approach. In *System Sciences, 2009. HICSS '09. 42nd Hawaii International Conference on* (pp. 1–10).

Harmon, R., Raffo, D., & Faulk, S. (2005). Value-based pricing for new software products: strategy insights for developers. In *Proc. Portland Internat. Conf. on Management of Eng. and Technol.(PICMET'04)(Seoul, Kor., 2004)*. Citeseer.

Hazledine, T. (2017). Mixed pricing in monopoly and oligopoly: theory and implications for merger analysis. *New Zealand Economic Papers*, *51*(2), 122–135. https://doi.org/10.1080/00779954.2017.1299198

Heide, J. B. (2003). Plural governance in industrial purchasing. *Journal of Marketing*, *67*(4), 18–29.

Heide, J. B., Kumar, A., & Wathne, K. H. (2013). Concurrent sourcing, governance mechanisms, and performance outcomes in industrial value chains. *Strategic Management Journal*, *35*(8), 1164–1185.

Heikkilä, J., Tyrväinen, P., & Heikkilä, M. (2010). Designing for performance-a technique for business model estimation. *Proceedings of EBRF; 1797-190X*.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, *28*(1), 75–105.

Hinterhuber, A. (2004). Towards value-based pricing: An integrative framework for decision making. *Industrial Marketing Management*, *33*(8), 765–778. https://doi.org/10.1016/j.indmarman.2003.10.006

Hinterhuber, A., & Liozu, S. M. (2014). Is innovation in pricing your next source of competitive advantage? *Business Horizons*, *57*(3), 413–423. https://doi.org/10.1016/j.bushor.2014.01.002

Hinterhuber, A., & Liozu, S. M. (2017). The micro-foundations of pricing. *Journal of Business Research*, *76*(Supplement C), 159–162. https://doi.org/10.1016/j.jbusres.2016.11.018

Hinz, O., Hann, I.-H., & Spann, M. (2011). Price discrimination in e-commerce? An examination of dynamic pricing in name-your-own price markets. *Mis Quarterly*, 81–98.

Hitt, L. M., & Chen, P. (2005). Bundling with customer self-selection: A simple approach to bundling low-marginal-cost goods. *Management Science*, 1481–1493.

Huang, K.-C., & Shen, B.-J. (2015). Service deployment strategies for efficient execution of composite SaaS applications on cloud platform. *Journal of Systems and Software*, *107*, 127–141. http://dx.doi.org/10.1016/j.jss.2015.05.050

Hunter, W. G., Hunter, J. S., & George, E. (1978). *Statistics for experimenters: an introduction to design, data analysis, and model building*. Wiley New York.

Huyskens, C., & Loebbecke, C. (2006). Empirically Evaluating Determinants of Netsourcing as Innovative eBusiness Sourcing Opportunity (pp. 1–16). Presented at the 19th Bled eConference.

International Data Corporation. (2015). Public Cloud Computing to Reach Nearly $70 billion in 2015 Worldwide, According to IDC. Retrieved 6 October 2015, from http://www.idc.com/getdoc.jsp?containerId=prUS25797415

Iveroth, E., Westelius, A., Petri, C.-J., Olve, N.-G., Cöster, M., & Nilsson, F. (2012). How to differentiate by price: Proposal for a five-dimensional model. *European Management Journal*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0263237312000680

Iveroth, E., Westelius, A., Petri, C.-J., Olve, N.-G., Cöster, M., & Nilsson, F. (2013). How to differentiate by price: Proposal for a five-dimensional model. *European Management Journal*, *31*(2), 109–123. https://doi.org/10.1016/j.emj.2012.06.007

Iyer, B., & Henderson, J. C. (2010). Preparing for the Future: Understanding the Seven Capabilities Cloud Computing. *MIS Quarterly Executive*, *9*(2), 117–131.

Jacobides, M. G., & Billinger, S. (2006). Designing the boundaries of the firm: From “make, buy, or ally” to the dynamic benefits of vertical architecture. *Organization Science*, *17*(2), 249–261.

Jacobs, D. (2005). Enterprise Software As Service. *Queue*, *3*(6), 36–42. https://doi.org/10.1145/1080862.1080875

Järvinen, P. (2001). *On research methods*. Opinpajan kirja.

Järvinen, P. (2008). Mapping research questions to research methods. In *Advances in Information Systems Research, Education and Practice* (pp. 29–41). Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-0-387-09682-7-9_3

Jhang-Li, J.-H., & Chiang, I. R. (2015). Resource allocation and revenue optimization for cloud service providers. *Decision Support Systems*, *77*, 55–66. https://doi.org/10.1016/j.dss.2015.04.008

Jiekak, S., Kermarrec, A.-M., Le Scouarnec, N., Straub, G., & Van Kempen, A. (2013). Regenerating codes: A system perspective. *ACM SIGOPS Operating Systems Review*, *47*(2), 23–32.

Johnson, M., Christensen, C., & Kagermann, H. (2008). Reinventing Your Business Model. *Harvard Business Review*, *86*(12), 50–59.

Juan-Verdejo, A., & Baars, H. (2013). Decision support for partially moving applications to the cloud: the example of business intelligence. In *Proceedings of the 2013 international workshop on Hot topics in cloud services* (pp. 35–42). ACM.

Kaltenecker, N., Hess, T., & Huesig, S. (2015). Managing potentially disruptive innovations in software companies: Transforming from On-premises to the On-demand. *The Journal of Strategic Information Systems*, *24*(4), 234–250. https://doi.org/10.1016/j.jsis.2015.08.006

Kamoun, F. (2008). Rethinking the business model with RFID. *Communications of the Association for Information Systems*, *22*(1), 35.

Kannisto, P. (2017). Sharing for profit: A new business model? *Annals of Tourism Research*, *66*(Supplement C), 206–208. https://doi.org/10.1016/j.annals.2017.07.003

Kaplan, B., & Duchon, D. (1988). Combining qualitative and quantitative methods in information systems research: a case study. *MIS Quarterly*, 571–586.

Kasae, Y., & Oguchi, M. (2013). Proposal for an optimal job allocation method for data-intensive applications based on multiple costs balancing in a hybrid cloud environment. In *Proceedings of the 7th International Conference on Ubiquitous Information Management and Communication* (p. 5). ACM.

Kashef, M. M., & Altmann, J. (2012). A cost model for hybrid clouds. In *Economics of Grids, Clouds, Systems, and Services* (pp. 46–60). Springer.

Khajeh-Hosseini, A., Greenwood, D., Smith, J. W., & Sommerville, I. (2012). The Cloud Adoption Toolkit: supporting cloud adoption decisions in the enterprise. *Software: Practice and Experience - Special Issue on Software Architectures and Application Development Environments for Cloud Computing*, *42*(4), 447–465.

Khajeh-Hosseini, A., Sommerville, I., Bogaerts, J., & Teregowda, P. (2011). Decision support tools for cloud migration in the enterprise. In *IEEE International Conference on Cloud Computing (CLOUD)* (pp. 541–548). IEEE.

Kittlaus, H. B., & Clough, P. N. (2009). *Software product management and pricing: Key success factors for software organizations*. Springer. Retrieved from http://www.google.com/books?hl=en&lr=&id=ZA08TJnu-e0C&oi=fnd&pg=PR2&dq=software+product+management+and+pricing&ots=dQPwT7baES&sig=0eMdfmi0_pRgfQl62_dZsNg8G0Y

Klems, M., Nimis, J., & Tai, S. (2009). Do clouds compute? A framework for estimating the value of cloud computing. In *Designing E-Business Systems. Markets, Services, and Networks* (pp. 110–123). Springer.

Ko, S. Y., Jeon, K., & Morales, R. (2011). The HybrEx model for confidentiality and privacy in cloud computing. In *Proceedings of the 3rd USENIX Conference on Hot Topics in Cloud Computing*. Portland, OR: USENIX Association.

Koomey, J., Brill, K., Turner, P., Stanley, J., & Taylor, B. (2007). A simple model for determining true total cost of ownership for data centers. *Uptime Institute White Paper, Version*, *2*.

Kotlarsky, J., Scarbrough, H., & Oshri, I. (2014). Coordinating Expertise Across Knowledge Boundaries in Offshore-Outsourcing Projects: The Role of Codification. *MIS Quarterly*, *38*(2), 607–627.

Kratzke, N. (2012). Cloud Computing Costs and Benefits. In *Cloud Computing and Services Science* (pp. 185–203). Springer.

Krzeminska, A., Hoetker, G., & Mellewigt, T. (2013). Reconceptualizing plural sourcing. *Strategic Management Journal*, *34*(13), 1614–1627.

Lacity, M. C., Khan, S., Yan, A., & Willcocks, L. P. (2010). A review of the IT outsourcing empirical literature and future research directions. *J Inf Technol*, *25*(4), 395–433.

Lacity, M. C., Solomon, S., Yan, A., & Willcocks, L. P. (2011). Business process outsourcing studies: a critical review and research directions. *Journal of Information Technology*, *26*(4), 221–258.

Lambrecht, A., & Skiera, B. (2006). Paying Too Much and Being Happy About It: Existence, Causes, and Consequences of Tariff-Choice Biases. *Journal of Marketing Research*, *43*(2), 212–223. https://doi.org/10.1509/jmkr.43.2.212

Lambrecht, B. M., Pawlina, G., & Teixeira, J. C. A. (2016). Making, Buying, and Concurrent Sourcing: Implications for Operating Leverage and Stock Beta. *Review of Finance*, *20*(3), 1013–1043. https://doi.org/10.1093/rof/rfv027

Lehmann, S., & Buxmann, P. (2009). Pricing Strategies of Software Vendors. *Business & Information Systems Engineering*, *1*(6), 452–462.

Lehmann, S., Draisbach, T., Buxmann, P., & Dörsam, P. (2012). Pricing of Software as a Service–An Empirical Study in View of the Economics of Information Theory. *Software Business*, 1–14.

Lehmann-Ortega, L., & Schoettl, J.-M. (2005). From buzzword to managerial tool: The role of business models in strategic innovation. *CLADEA, Santiago de Chile*, 1–14.

Lei, H., Zhang, T., Liu, Y., Zha, Y., & Zhu, X. (2015). SGEESS: Smart green energy-efficient scheduling strategy with dynamic electricity price for data center. *Journal of Systems and Software*, *108*, 23–38. http://dx.doi.org/10.1016/j.jss.2015.06.026

Leimeister, S., Böhm, M., Riedl, C., & Krcmar, H. (2010). The Business Perspective of Cloud Computing: Actors, Roles and Value Networks. In *ECIS* (p. 56).

Lenk, A., Klems, M., Nimis, J., Tai, S., & Sandholm, T. (2009). What's Inside the Cloud? An Architectural Map of the Cloud Landscape. In *Proceedings of the 2009 ICSE Workshop on Software Engineering Challenges of Cloud Computing* (pp. 23–31). Washington, DC, USA: IEEE Computer Society. https://doi.org/10.1109/CLOUD.2009.5071529

Leong, L., Toombs, D., Gill, B., Petri, G., & Haynes, T. (2014). *Magic Quadrant for Cloud Infrastructure as a Service*. Gartner.

Li, S., Cheng, H. K., Duan, Y., & Yang, Y.-C. (2017). A Study of Enterprise Software Licensing Models. *Journal of Management Information Systems*, *34*(1), 177–205. https://doi.org/10.1080/07421222.2017.1297636

Lilienthal, M. (2013). A Decision Support Model for Cloud Bursting. *Business & Information Systems Engineering*, *5*(2), 71–81.

Liu, Y., Cheng, H. K., Tang, Q. C., & Eryarsoy, E. (2011). Optimal software pricing in the presence of piracy and word-of-mouth effect. *Decision Support Systems*, *51*(1), 99–107.

Long, S., Zhao, Y., & Chen, W. (2014). A three-phase energy-saving strategy for cloud storage systems. *Journal of Systems and Software*, *87*, 38–47. http://dx.doi.org/10.1016/j.jss.2013.08.018

Luoma, E. (2013). Examining business models of Software-as-a-Service companies. Retrieved from https://jyx.jyu.fi/dspace/handle/123456789/42663

Luoma, E., & Nyberg, T. (2011). Four scenarios for adoption of cloud computing in china. In *ECIS* (p. 123). Retrieved from http://aisel.aisnet.org/cgi/viewcontent.cgi?article=1122&context=ecis2011

Luoma, E., Rönkkö, M., & Tyrväinen, P. (2012). Current software-as-a-service business models: evidence from Finland. In *International Conference of Software Business* (pp. 181–194). Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-30746-1_15

Magretta, J. (2002). Why business models matter. Retrieved from http://rushkolnik.ru/tw_files2/urls_2/135/d-134406/7z-docs/10.pdf

Mahadevan, B. (2000). Business Models for Internet-Based E-Commerce: An Anatomy. *California Management Review*, *42*. https://doi.org/10.2307/41166053

Mansouri, Y., & Buyya, R. (2016). To move or not to move: Cost optimization in a dual cloud-based storage architecture. *Journal of Network and Computer Applications*, *75*(Supplement C), 223–235. https://doi.org/10.1016/j.jnca.2016.08.029

Mao, B., Jiang, H., Wu, S., Fu, Y., & Tian, L. (2014). Read-performance optimization for deduplication-based storage systems in the cloud. *ACM Transactions on Storage (TOS)*, *10*(2), 6.

Markoff, J., Shapiro, G., & Weitman, S. R. (1975). Toward the Integration of Content Analysis and General Methodology. *Sociological Methodology*, *6*, 1–58. https://doi.org/10.2307/270893

Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J., & Ghalsasi, A. (2011). Cloud computing—The business perspective. *Decision Support Systems*, *51*(1), 176–189.

Martens, B., Walterbusch, M., & Teuteberg, F. (2012). Costing of cloud computing services: a total cost of ownership approach. In *45th Hawaii International Conference on System Science (HICSS)* (pp. 1563–1572). IEEE.

Mastroeni, L., & Naldi, M. (2011). Long-range Evaluation of Risk in the Migration to Cloud Storage. In *IEEE 13th Conference on Commerce and Enterprise Computing (CEC)* (pp. 260–266). https://doi.org/10.1109/CEC.2011.47

Mastroeni, L., & Naldi, M. (2012). Pricing of insurance policies against cloud storage price rises. *ACM SIGMETRICS Performance Evaluation Review*, *40*(2), 42–45.

Mazhelis, O. (2012). Costs of Using Hybrid Cloud Infrastructure: Towards a General Framework. In *Software Business* (pp. 261–266). Springer.

Mazhelis, O., & Tyrväinen, P. (2011). Role of Data Communications in Hybrid Cloud Costs. In *Proceedings of the 37th EUROMICRO Conference on Software Engineering and Advanced Applications*. Oulu, Finland.

Mazhelis, O., & Tyrväinen, P. (2012). Economic aspects of hybrid cloud infrastructure: User organization perspective. *Information Systems Frontiers*, *14*(4), 845–869.

Mazhelis, O., Tyrväinen, P., Tan, K. E., & Hiltunen, J. (2012). Assessing Cloud Infrastructure Costs in Communications-Intensive Applications. In *Cloud Computing and Services Science* (pp. 277–293). Springer.

Mell, P., & Grance, T. (2011). The NIST definition of cloud computing.

Mian, R., Martin, P., Zulkernine, F., & Vazquez-Poletti, J. L. (2012). Estimating resource costs of data-intensive workloads in public clouds. In *Proceedings of the 10th International Workshop on Middleware for Grids, Clouds and e-Science* (p. 3:1–3:6). Montreal, Quebec, Canada: ACM.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Sage. Retrieved from http://www.google.com/books?hl=en&lr=&id=U4lU_-wJ5QEC&oi=fnd&pg=PR12&dq=Qualitative+data+analysis:+An+expanded+sourcebook.+Sage.&ots=kC_D6GQV0S&sig=jsuapByyKPrclcqTvtv6muPJYPk

Misra, S. C., & Mondal, A. (2011). Identification of a company's suitability for the adoption of cloud computing and modelling its corresponding Return on Investment. *Mathematical and Computer Modelling*, *53*(3), 504–521.

Mols, N. P. (2010). Economic explanations for concurrent sourcing. *Journal of Purchasing and Supply Management*, *16*(1), 61–69.

Mols, N. P. (2017). Concurrent sourcing and supplier opportunism. *International Journal of Procurement Management*, *10*(1), 89–105. https://doi.org/10.1504/IJPM.2017.080917

Mols, N. P., Hansen, J. R., & Villadsen, A. R. (2012). Plural governance: The effect of internal production on supplier performance. *Industrial Marketing Management*, *41*(5), 874–885.

Morris, C. (2011). *Data Backup and Archiving on the HFS*.

Morris, M., Schindehutte, M., & Allen, J. (2005). The entrepreneur's business model: toward a unified perspective. *Journal of Business Research*, *58*, 726–735.

Moschakis, I. A., & Karatza, H. D. (2015). Multi-criteria scheduling of Bag-of-Tasks applications on heterogeneous interlinked clouds with simulated annealing. *Journal of Systems and Software*, *101*, 1–14. http://dx.doi.org/10.1016/j.jss.2014.11.014

Muniswamy-Reddy, K.-K., Macko, P., & Seltzer, M. (2009). Making a cloud provenance-aware. In *1st Workshop on the Theory and Practice of Provenance*.

Muniswamy-Reddy, K.-K., & Seltzer, M. (2010). Provenance as first class cloud data. *ACM SIGOPS Operating Systems Review*, *43*(4), 11–16.

Myers, M. D. (1997). Qualitative research in information systems. *Management Information Systems Quarterly*, *21*(2), 241–242.

Nadjaran, T., Sinnott, R. O., & Buyya, R. (2018). Resource provisioning for data-intensive applications with deadline constraints on hybrid clouds using Aneka. *Future Generation Computer Systems*, *79*, 765–775. https://doi.org/10.1016/j.future.2017.05.042

Naldi, M., & Mastroeni, L. (2016). Economic decision criteria for the migration to cloud storage. *European Journal of Information Systems*, *25*(1), 16–28. https://doi.org/10.1057/ejis.2014.34

Nufire, T. (2011). *Petabytes on a Budget v2.0: Revealing More Secrets*.

Ojala, A. (2013). Software-as-a-Service Revenue Models. *IT Professional*, 15(3), 54-59.

Ojala, A. (2012). Software Renting in the Era of Cloud Computing. In *Cloud Computing (CLOUD), 2012 IEEE 5th International Conference on* (pp. 662–669). IEEE.

Ojala, A. (2016a). Adjusting Software Revenue and Pricing Strategies in the Era of Cloud Computing. *Journal of Systems and Software*, *122*. https://doi.org/10.1016/j.jss.2016.08.070

Ojala, A. (2016b). Business models and opportunity creation: How IT entrepreneurs create and develop business models under uncertainty. *Information Systems Journal*, *26*(5), 451–476.

Osterwalder, A. (2004). The business model ontology: A proposition in a design science approach.

Osterwalder, A., Pigneur, Y., & Tucci, C. L. (2005). Clarifying business models: Origins, present, and future of the concept. *Communications of the Association for Information Systems*, *16*(1), 1–25.

Pal, R., & Hui, P. (2013). Economic models for cloud service markets: Pricing and Capacity planning. *Theoretical Computer Science*, *496*(Supplement C), 113–124. https://doi.org/10.1016/j.tcs.2012.11.001

Palankar, M. R., Iamnitchi, A., Ripeanu, M., & Garfinkel, S. (2008). Amazon S3 for science grids: a viable solution? In *Proceedings of the 2008 international workshop on Data-aware distributed computing* (pp. 55–64). ACM.

Paré, G. (2004). Investigating information systems with positivist case research. *Communications of the Association for Information Systems*, *13*(1), 18.

Parmigiani, A. (2003). *Concurrent sourcing: When do firms both make and buy?* Duke University.

Parmigiani, A. (2007). Why do firms both make and buy? An investigation of concurrent sourcing. *Strategic Management Journal*, *28*(3), 285–311.

Parmigiani, A., & Mitchell, W. (2009). Complementarity, capabilities, and the boundaries of the firm: the impact of within-firm and interfirm expertise on concurrent sourcing of complementary components. *Strategic Management Journal*, *30*(10), 1065–1091.

Pettigrew, A. M. (1990). Longitudinal field research on change: theory and practice. *Organization Science*, *1*(3), 267–292.

Phaphoom, N., Wang, X., Samuel, S., Helmer, S., & Abrahamsson, P. (2015). A survey study on major technical barriers affecting the decision to adopt cloud services. *Journal of Systems and Software*, *103*, 167–181. http://dx.doi.org/10.1016/j.jss.2015.02.002

Piercy, N. F., Cravens, D. W., & Lane, N. (2010). Thinking strategically about pricing decisions. *Journal of Business Strategy*, *31*(5), 38–48.

Pindyck, R. S., & Rubinfeld, D. L. (1995). *Microeconomics*. Englewood Cliffs, New Jersey: Prentice Hall.

Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: a critical review of the literature and recommended remedies. *Journal of Applied Psychology*, *88*(5), 879.

Popp, K. A. (2011). Software Industry Business Models. *IEEE Software; Los Alamitos*, *28*(4), 26–30. http://dx.doi.org/10.1109/MS.2011.52

Porcher, S. (2016). Neither Market Nor Hierarchy: Concurrent Sourcing in Water Public Services. *Journal of Public Administration Research and Theory*, *26*(4), 800–812. https://doi.org/10.1093/jopart/muw037

Porter, M. E. (1980). *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. Free Press, New York.

Porter, M. E. (2001). OT COPY. *Harvard Business Review*, 1.

Puranam, P., Gulati, R., & Bhattacharya, S. (2013). How much to make and how much to buy? An analysis of optimal plural sourcing strategies. *Strategic Management Journal*, *34*(10), 1145–1161.

Quiroz, A., Kim, H., Parashar, M., Gnanasambandam, N., & Sharma, N. (2009). Towards autonomic workload provisioning for enterprise grids and clouds. In *The 10th IEEE/ACM International Conference on Grid Computing* (pp. 50–57). IEEE.

Rajala, R., Rossi, M., & Tuunainen, V. (2003). A Framework for Analysing Software Business Models.

Rajala, R., & Westerlund, M. (2007). Business models – a new perspective on firms' assets and capabilities: Observations from the Finnish software industry. *Entrepreneurship and Innovation*, *8*(2), 115–125.

Rao, K. V. P. R., Reddy, V. K., & Yakoob, S. K. (2018). Dynamic Secure Deduplication in Cloud Using Genetic Programming. In *Data Engineering and Intelligent Computing* (pp. 493–502). Springer, Singapore. https://doi.org/10.1007/978-981-10-3223-3_48

RightScale. (2017). *RightScale 2017 State of the Cloud Report*.

Risch, M., & Altmann, J. (2008). Cost Analysis of Current Grids and Its Implications for Future Grid Markets. In J. Altmann, D. Neumann, & F. T (Eds.), *Proceedings of the 5th international workshop on Grid Economics and*

Business Models (pp. 13–27). Las Palmas de Gran Canaria, Spain: Springer-Verlag.

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

Ruiz-Alvarez, A., & Humphrey, M. (2011). An automated approach to cloud storage service selection. In *Proceedings of the 2nd international workshop on Scientific cloud computing* (pp. 39–48). ACM.

Ruiz-Alvarez, A., & Humphrey, M. (2012). A model and decision procedure for data storage in cloud computing. In *The 12th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid)* (pp. 572–579). IEEE.

Saarikallio, M., & Tyrväinen, P. (2014). Following the Money: Revenue Stream Constituents in Case of Within-firm Variation. In *Software Business. Towards Continuous Value Delivery* (pp. 88–99). Springer, Cham. https://doi.org/10.1007/978-3-319-08738-2_7

Sako, M., Chondrakis, G., & M. Vaaler, P. (2013). How Do Firms Balance Making and Buying? The Case of Legal Services Sourcing by Fortune 500 Companies. *ForthComing*.

Schief, M., & Buxmann, P. (2012). Business Models in the Software Industry. In *2012 45th Hawaii International Conference on System Sciences* (pp. 3328–3337). https://doi.org/10.1109/HICSS.2012.140

Schramm, T., Wright, J., Seng, D., & Jones, D. (2010). Six questions every supply chain executive should ask about cloud computing. *Accenture Institute for High Performance*, 765–778.

Schwarz, A., Jayatilaka, B., Hirschheim, R., & Goles, T. (2009). A Conjoint Approach to Understanding IT Application Services Outsourcing. *Journal of the Association for Information Systems*, *10*(10), 748–781.

Scott M. Fulton, I. (2011). *IDC: Business Spending for Cloud Storage to Triple by 2015*.

Seddon, P., Lewis, G., Freeman, P., & Shanks, G. (2004). The Case for Viewing Business Models as Abstractions of Strategy. *Communications of the Association for Information Systems*, *13*, 427–442.

Senyo, P. K., Addae, E., & Boateng, R. (2018). Cloud computing research: A review of research themes, frameworks, methods and future research directions. *International Journal of Information Management*, *38*(1), 128–139. https://doi.org/10.1016/j.ijinfomgt.2017.07.007

Shapiro, C., & Varian, H. R. (1998). *Information rules: a strategic guide to the network economy*. Harvard Business Press.

Shifrin, M., Atar, R., & Cidon, I. (2013). Optimal scheduling in the hybrid-cloud. In *IFIP/IEEE International Symposium on Integrated Network Management (IM 2013)* (pp. 51–59). IEEE.

Shipley, D., & Jobber, D. (2001). Integrative Pricing via the Pricing Wheel. *Industrial Marketing Management*, *30*(3), 301–314. https://doi.org/10.1016/S0019-8501(99)00098-X

Silva, L. A. B., Costa, C., & Oliveira, J. L. (2013). A common {API} for delivering services over multi-vendor cloud resources. *Journal of Systems and Software*, *86*(9), 2309–2317. http://dx.doi.org/10.1016/j.jss.2013.04.037

Smith, J. E., & Nair, R. (2005). The architecture of virtual machines. *Computer*, *38*(5), 32–38.

Spiegel, Y. (1997). Second degree price discrimination. *Tel Aviv University*.

Stake, R. E. (1995). The art of case study research. Retrieved from http://www.citeulike.org/group/7218/article/2937468

Stemler, S. (2001). An overview of content analysis. *Practical Assessment, Research & Evaluation*, *7*(17), 137–146.

Stuckenberg, S., Fielt, E., & Loser, T. (2011). The impact of software-as-a-service on business models of leading software vendors: experiences from three exploratory case studies. In *Proceedings of the 15th Pacific Asia Conference on Information Systems (PACIS 2011)*. Retrieved from http://eprints.qut.edu.au/43815/

Sun, K., & Li, Y. (2013). Effort Estimation in Cloud Migration Process. In *Service Oriented System Engineering (SOSE), 2013 IEEE 7th International Symposium on* (pp. 84–91). IEEE.

Sun, Y., White, J., Eade, S., & Schmidt, D. C. (2015). ROAR: A QoS-oriented modeling framework for automated cloud resource allocation and optimization. *Journal of Systems and Software*. http://dx.doi.org/10.1016/j.jss.2015.08.006

Sundararajan, A. (2004). Nonlinear Pricing of Information Goods. *Management Science*, *50*(12), 1660–1673.

Susarla, A., Barua, A., & Whinston, A. (2009). A Transaction Cost Perspective of the 'Software As a Service' Business Model. *J. Manage. Inf. Syst.*, *26*(2), 205–240. https://doi.org/10.2753/MIS0742-1222260209

Swamidass, P. M. (1986). Manufacturing strategy: its assessment and practice. *Journal of Operations Management*, *6*(3), 471–484.

Tak, B. C., Urgaonkar, B., & Sivasubramaniam, A. (2011). To move or not to move: The economics of cloud computing. In *Proceedings of the 3rd USENIX conference on Hot topics in cloud computing* (pp. 5–5). USENIX Association.

Tak, B. C., Urgaonkar, B., & Sivasubramaniam, A. (2013). Cloudy with a Chance of Cost Savings. *IEEE Transactions on Parallel and Distributed Systems*, *24*(6), 1223–1233.

Tang, C. S., & Deo, S. (2008). Rental price and rental duration under retail competition. *European Journal of Operational Research*, *187*(3), 806–828. https://doi.org/10.1016/j.ejor.2006.03.061

Tang, L., & Chen, H. (2017). Joint Pricing and Capacity Planning in the IaaS Cloud Market. *IEEE Transactions on Cloud Computing*, *5*(1), 57–70. https://doi.org/10.1109/TCC.2014.2372811

Teece, D. (2010). Business Models, Business Strategy and Innovation. *Long Range Planning*, *43*, 172–194.

Timmers, P. (1998). Business models for electronic markets. *Electronic Markets*, *8*(2), 3–8.
Tiwana, A., & Kim, S. K. (2016). Concurrent IT Sourcing: Mechanisms and Contingent Advantages. *Journal of Management Information Systems*, *33*(1), 101–138. https://doi.org/10.1080/07421222.2016.1172456
Töytäri, P., Keränen, J., & Rajala, R. (2017). Barriers to implementing value-based pricing in industrial markets: A micro-foundations perspective. *Journal of Business Research*, *76*(Supplement C), 237–246. https://doi.org/10.1016/j.jbusres.2016.04.183
Töytäri, P., Rajala, R., & Alejandro, T. B. (2015). Organizational and institutional barriers to value-based pricing in industrial relationships. *Industrial Marketing Management*, *47*(Supplement C), 53–64. https://doi.org/10.1016/j.indmarman.2015.02.005
Trummer, I., Leymann, F., Mietzner, R., & Binder, W. (2010). Cost-Optimal Outsourcing of Applications into the Clouds. In *The Second International Conference on Cloud Computing Technology and Science (CloudCom)* (pp. 135–142). https://doi.org/10.1109/CloudCom.2010.64
Truong, H.-L., & Dustdar, S. (2010). Composable cost estimation and monitoring for computational applications in cloud computing environments. *Procedia Computer Science*, *1*(1), 2175–2184.
Turner, W. P., & Seader, J. H. (2006). *Dollars per kW plus dollars per square foot are a better datacenter cost model than dollars per square foot alone*.
TwinStrata. (2013). *A Snapshot into Cloud Storage Adoption*.
Tyrväinen, P., & Selin, J. (2011). How to sell SaaS: a model for main factors of marketing and selling software-as-a-service. In *Software Business* (pp. 2–16). Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-21544-5_2
Valtakoski, A. (2015). Initiation of buyer–seller relationships: The impact of intangibility, trust and mitigation strategies. *Industrial Marketing Management*, *44*, 107–118.
Van den Bossche, R., Vanmechelen, K., & Broeckhove, J. (2010). Cost-Optimal Scheduling in Hybrid IaaS Clouds for Deadline Constrained Workloads. In *3th IEEE International Conference on Cloud Computing* (pp. 228–235). Los Alamitos, CA, USA: IEEE Computer Society.
van der Rest, J.-P., Roper, A., & Wang, X. L. (2018). Why is a change of company pricing policy so hard to implement? *International Journal of Hospitality Management*, *69*(Supplement C), 30–40. https://doi.org/10.1016/j.ijhm.2017.10.010
Van Putten, B.-J., & Schief, M. (2013). The relation between dynamic business models and business cases. In *Supporting Reuse in Business Case Development* (pp. 118–133). Springer. Retrieved from https://link.springer.com/chapter/10.1007/978-3-658-01171-0_8
Varian, H. R. (1996). Differential pricing and efficiency. *First Monday*, *1*(2–5).
Varian, H. R. (1997). Versioning information goods. *University of California, Berkeley*.

Varian, H. R. (2000). Buying, sharing and renting information goods. *Journal of Industrial Economics*, *48*(4), 473–488.

Vecchiola, C., Calheiros, R. N., Karunamoorthy, D., & Buyya, R. (2012). Deadline-driven provisioning of resources for scientific applications in hybrid clouds with Aneka. *Future Generation Computer Systems*, *28*(1), 58–65.

Veit, D., Clemons, E., Benlian, A., Buxmann, P., Hess, T., Kundisch, D., … Spann, M. (2014). Business Models. *Business & Information Systems Engineering*, *6*(1), 45–53. https://doi.org/10.1007/s12599-013-0308-y

Venters, W., & Whitley, E. A. (2012). A critical review of cloud computing: researching desires and realities. *Journal of Information Technology*, *27*(3), 179–197. http://dx.doi.org/10.1057/jit.2012.17

Viswanathan, S., & Anandalingam, G. (2005). Pricing strategies for information goods. *Sadhana*, *30*(2), 257–274.

Voelpel, S. C., Leibold, M., & Tekie, E. B. (2004). The wheel of business model reinvention: how to reshape your business model to leapfrog competitors. *Journal of Change Management*, *4*(3), 259–276.

Walker, E., Brisken, W., & Romney, J. (2010). To Lease or Not to Lease from Storage Clouds. *Computer*, *43*(4), 44–50.

Walterbusch, M., Martens, B., & Teuteberg, F. (2013). Evaluating cloud computing services from a total cost of ownership perspective. *Management Research Review*, *36*(6), 613–638.

Wang, W., Liang, B., & Li, B. (2013). Revenue maximization with dynamic auctions in IaaS cloud markets. In *2013 IEEE/ACM 21st International Symposium on Quality of Service (IWQoS)* (pp. 1–6). https://doi.org/10.1109/IWQoS.2013.6550265

Wang, W.-J., Chang, Y.-S., Lo, W.-T., & Lee, Y.-K. (2013). Adaptive scheduling for parallel tasks with QoS satisfaction for hybrid cloud environments. *The Journal of Supercomputing*, *66*(2), 783–811.

Wang, W.-J., Lo, Y.-M., Chen, S.-J., & Chang, Y.-S. (2012). Intelligent application migration within a self-provisioned hybrid cloud environment. In *Computer Science and Convergence* (pp. 295–303). Springer.

Water, H. van de, & Peet, H. P. van. (2006). A decision support model based on the Analytic Hierarchy Process for the Make or Buy decision in manufacturing. *Journal of Purchasing and Supply Management*, *12*(5), 258–271.

Weber, R. P. (1990). *Basic content analysis*. Sage.

Weigelt, C., & Sarkar, M. (2012). Performance implications of outsourcing for technological innovations: managing the efficiency and adaptability trade-off. *Strategic Management Journal*, *33*(2), 189–216.

Weinhardt, P. D. C., Anandasivam, D.-I.-W. A., Blau, D. B., Borissov, D.-I. N., Meinl, D.-M. T., Michalk, D.-I.-W. W., & Stößer, D. J. (2009). Cloud Computing – A Classification, Business Models, and Research Directions. *Business & Information Systems Engineering*, *1*(5), 391–399. https://doi.org/10.1007/s12599-009-0071-2

Weinman, J. (2011). Cloudonomics: A Rigorous Approach to Cloud Benefit Quantification. *The Journal of Software Technology*, *14*(4), 10–18.

Weinman, J. (2012). *Cloudonomics: The Business Value of Cloud Computing*. John Wiley & Sons.

Willcocks, L. P., Venters, W., & Whitley, E. A. (2013). Cloud sourcing and innovation: slow train coming?: A composite research study. *Strategic Outsourcing: An International Journal*, *6*(2), 184–202. https://doi.org/10.1108/SO-04-2013-0004

Williamson, O. E. (1985). *The Economic Institutions of Capitalism*. The Free Press, New York.

Winsberg, E. (2003). Simulated experiments: Methodology for a virtual world. *Philosophy of Science*, *70*(1), 105–125.

Wirtz, B. W., Pistoia, A., Ullrich, S., & Göttel, V. (2016). Business Models: Origin, Development and Future Research Perspectives. *Long Range Planning*, *49*(1), 36–54. https://doi.org/10.1016/j.lrp.2015.04.001

Wirtz, B. W., Schilke, O., & Ullrich, S. (2010). Strategic development of business models: implications of the Web 2.0 for creating value on the internet. *Long Range Planning*, *43*(2), 272–290.

Xin, M., & Levina, N. (2008). Software-as-a-service model: Elaborating client-side adoption factors. In *Proceedings of the 29th International Conference on Information Systems, R. Boland, M. Limayem, B. Pentland,(eds), Paris, France*. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1319488

Yao, Y. (2002). Client Relationship Development witf Different Sectors of Application Service Providers: an Extended Research Model. *Eighth Americas Conference on Information Systems*, 2286–2294.

Yin, R. K. (2009). *Case study research: Design and methods*. CA: SAGE Publications.

Yuan, D., Yang, Y., Liu, X., & Chen, J. (2010). A cost-effective strategy for intermediate data storage in scientific cloud workflow systems. In *Parallel & Distributed Processing (IPDPS), 2010 IEEE International Symposium on* (pp. 1–12). IEEE.

Yuan, D., Yang, Y., Liu, X., & Chen, J. (2011). On-demand minimum cost benchmarking for intermediate dataset storage in scientific cloud workflow systems. *Journal of Parallel and Distributed Computing*, *71*(2), 316–332.

Zhang, H., Jiang, G., Yoshihira, K., Chen, H., & Saxena, A. (2009). Intelligent workload factoring for a hybrid cloud computing model. In *Proceedings of the 2009 Congress on Services - I* (pp. 701–708). Washington, DC, USA: IEEE Computer Society.

Zhang, H., Li, P., Zhou, Z., Wu, J., & Yu, X. (2014). A Privacy-aware Virtual Machine Migration Framework on Hybrid Clouds. *Journal of Networks*, *9*(5), 1086–1095.

Zhang, K., Zhou, X., Chen, Y., Wang, X., & Ruan, Y. (2011). Sedic: privacy-aware data intensive computing on hybrid clouds. In *Proceedings of the*

18th ACM conference on Computer and communications security (pp. 515–526). ACM.

Zhu, Y., & Zhang, J. (2012). Research on key technology for SaaS. In *Computer Science & Education (ICCSE), 2012 7th International Conference on* (pp. 207–210). Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6295058

Zott, C., Amit, R., & Massa, L. (2011). The Business Model: Recent Developments and Future Research. *Journal of Management*, *38*(1), 375–414.

ORIGINAL PAPERS

I

CLOUD SERVICES PRICING MODELS

by

Gabriella Laatikainen, Arto Ojala & Oleksiy Mazhelis, 2013

Proceedings of ICSOB 2013, pp. 117-129

Cloud services pricing models

Gabriella Laatikainen, Arto Ojala and Oleksiy Mazhelis

Department of Computer Science and Information Systems
University of Jyväskylä
Jyväskylä, Finland
gabriella.laatikainen@jyu.fi,arto.k.ojala@jyu.fi,mazhelis@jyu.fi

Abstract. Although a major condition for commercial success is a well-defined pricing strategy, cloud service providers face many challenges around pricing. Clearness and transparency in pricing is beneficial for all the actors in the ecosystem, where the currently existing abundance of different pricing models makes decision making difficult for service providers, partners, customers and competitors. In this paper, the SBIFT pricing model is evaluated and updated to cloud context. As a result, a 7-dimensional cloud pricing framework is proposed that helps clarifying the possible pricing models in order to let companies differentiate themselves from competitors by price. The framework can be used also as a tool for price model development and communication about cloud pricing. The taxonomy is based on a broad literature review and empirical research on currently used pricing models of 54 cloud providers.

Key words: pricing; revenue logic; cloud; SaaS; PaaS; IaaS

1 Introduction

One of the key conditions for commercial success of cloud services is the clearness and transparency of pricing for both customers and providers [1, 2]. Properly applied, a well-defined pricing strategy can change customers' behavior and it can determine the offering's position on the competitive market [3]. Pricing models influence not only the demand, but have an effect also on the way how users use the product or service, and have a long-term influence on customer relationships [4]. Pricing can also differentiate an offering from the competitors [5, 6] and this way increase the company's revenues and position in the market. Therefore pricing is a powerful strategic tool in manager's hands.

However, because of the rapid technology development and increasing competition in the global markets, price modeling for software products became very complex. A number of studies have also suggested that traditional pricing models are not applicable as such for pricing of software products (e.g. [7]) and the way of pricing software products is also changing [8]. Hence, there is a constantly changing labyrinth around software pricing with many different pricing solutions [8]. For this reason, cloud solution providers may face many challenges around pricing [9] and pricing of IT services is often a neglected topic for many IT managers [10].

For the above-mentioned reasons, there is a need for a clear and systematic pricing framework, developed especially for cloud industry, that helps decision makers find the proper pricing model and evaluate its alternatives, advantages and disadvantages. Hence, the aim of this study is to examine empirically the applicability of an existing pricing model in the context of cloud solutions and, if needed, propose possible modifications to the model. We seek to contribute to the literature of cloud computing by revealing the most popular pricing models used by 54 cloud solution providers. In addition, we propose a model that managers operating in cloud business can use as a tool to evaluate the proper pricing model for their solutions.

2 Related work

2.1 The SBIFT pricing model

A comprehensive taxonomy of pricing models has been proposed by Iveroth et al. [11], that defines pricing models as systems of price-related characteristics of the agreement between buyer and seller. Price models are described along 5 dimensions, that are listed without priority (see figure 1). According to the authors, price models can be described through the specification of the "positions" on each dimension. The taxonomy is called SBIFT model, that stands for the acronyms of the dimensions.

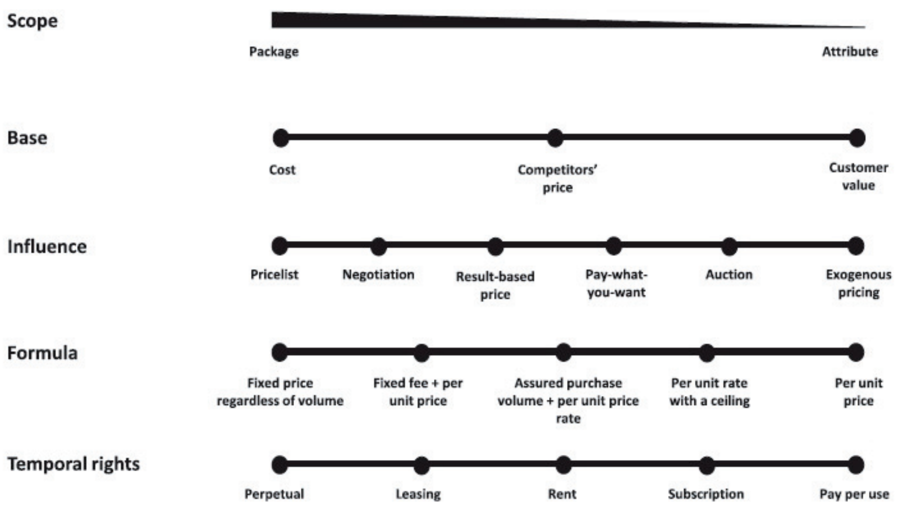


Fig. 1. The SBIFT model [11]

We chose to evaluate this model in cloud context, since it provides the most state-of-the-art and the most integrative work in the current pricing literature. The flexibility of this taxonomy makes it possible to create novel pricing models as a combination of different pricing elements. The model contains pricing elements also from the cloud- and software literature, hence it may be applied to the cloud services easily. The dimensions of the model are presented as follows.

The **Scope** dimension refers to the granularity of the offer. At the left side of the slider, a *Package* of products/services are priced; while the other extreme category is named *Attribute*, referring to the case when each unit of the offer is priced individually and buyers can decide upon buying them or not.

The **Base** dimension refers to the information base that dominates the pricing decisions. *Cost-based pricing* is the most widely used pricing method [12], where the seller determines the price floor based on the cost of developing, producing, distributing and selling the goods. Another pricing formation strategy is setting the price level according to *Competitor's price* of comparable products or services [13]. Using *Value-based* (demand-based) pricing strategies providers define their prices based on the customers' perceived value [10, 14, 15].

The **Influence** dimension reflects the ability of buyers and sellers to influence the price. If the price is decided by the provider alone, this is usually communicated through a *Pricelist*. If the price is set based on a *Negotiation* between the customer and the provider, then the starting point is also a pricelist but the buyer can influence the final price. The next option is *Result-based pricing*, where the price is determined based on some observable result of the product/service [11]. In an *Auction* the price is set based on the customers' willingness to pay and the sellers' influence on the price is limited. *Exogenous pricing* is used if circumstances beyond the sellers' and buyers' influence determine the price.

The **Formula** dimension refers to the connection between price and volume. With a *Fixed price regardless of volume* (flat-pricing, eat-all-what-you-can), customers pay a fixed price, that is independent from the used volume [16]. The *Fixed fee plus per unit rate* formula has two components: a fixed, predetermined, volume-independent part and a volume-dependent part. In case of *Assured purchase volume plus per unit rate*, a fixed amount of volume is priced with a fix price, and an overage price is charged for the extra consumption with the per unit rate. Using the *Per unit rate with a ceiling* formula, the per unit price has to be paid only until a certain consumption-level, and above that the usage is free of charge [11]. In case of *Per unit price*, units (or units per time) are associated with fixed price values and the customer pays this per unit price regardless of the quality or the economies of scale that the seller might encounter.

The **Temporal rights** dimension refers to the length of the time period when the user can use the offering. In case of *Perpetual* offering, the customer can use and own the goods as long as he wants [17, 18, 19]. When *Leasing*, customers buy the right to use the service/product for a fixed period and to buy it after the period on a predefined price. Through *Renting* the right is bought to use the product or service for a "rental" period, during which the customer does not get any updates or changes to the original product/service. On the other hand, in case of *Subscription*, buyers have the right to use the service/product for a period but they also get upgrades, enhancements, new functionalities or new content from the provider during this time. If the buyers pay every time they use the service or product, the seller applies *Pay per use* (pay-as-you-go) mechanism.

2.2 Software pricing

In software business there are three general revenue models, all including several pricing options. First revenue model, software licensing refers to the traditional way to buy the software. In software licensing, a customer buys a license that gives a right to use the software in a certain amount of computers or processors [17, 18]. In many cases, the length or amount of usage is not limited. Second revenue model, software renting, gives a right to use the software for a certain time period that is defined in the rent agreement [5]. The third model, pay-per-use enables software providers to charge customers based on the actual usage of the software [17].

Pricing in these above introduced revenue models may base on different aspects. Lehmann and Buxmann [7] introduced the following pricing parameters:

(i) *Price formation:* The seller determines the price base (cost-based, value-based or competition oriented) and the degree of interaction between the seller and buyer (unilateral or interactive).
(ii) *Structure of payment flow:* Payments may be done as single payments, through recurring payments or through a combination of these.
(iii) *Assessment base:* The number of pricing components, the usage-dependent and usage-independent assessment bases have to be defined.
(iv) *Price discrimination:* Sellers offer the same good to different buyers at different prices. Price discrimination may be first-degree (prices depend on each user's willingness-to-pay), second-degree (customers may choose one of the offered product-price combinations based on required quantity, software version or time), third-degree (market segmentation by the seller based on personal or regional conditions) or multidimensional (combination of these).
(v) *Price bundling:* Several items (services, products, rights, etc.) are bound together into an offering with a predetermined price. The offering may be pure bundling (the products are offered exclusively in a bundle), mixed bundling (goods may be bought as a package or separately), unbundling (products may be bought only separately) or customized bundling (customers choose the content of the bundle). In price bundling, software products, maintenance and support services may be packaged together. The degree of integration of the bundle items can be complementary, independent or they can substitute each other. The price level of the bundle can be additive (the price of the bundle is the sum of the prices of the items), superadditive (the price is greater than the sum of individual prices) or subadditive (lower price than the sum of individual prices).
(vi) *Dynamic pricing strategies:* The seller sets the price dynamically over time. For software products, penetration (setting low prices in the beginning and possibly increasing it later), follow-the-free (the product is free, revenues come from complementary services or extra functionalities) and skimming (high starting prices that may be gradually reduced) pricing strategies are the most important.

Summarizing, the items of SBIFT model [11] and the software pricing parameters [7] overlap each other: some dimensions and parameters refer to the same aspect (Scope-Price bundling, Base-Price determination), some dimensions offer more alternatives than the respective pricing parameter (Influence-Degree of interaction, Formula-Assessment base), one of the dimensions takes a different point-of-view than the respective parameter (Temporal rights-Structure of payment flow) and some parameters are missing from the SBIFT model (Price discrimination, Dynamic pricing strategies).

3 Methodology and data

In order to evaluate the applicability of the SBIFT model empirically in cloud context and to get an insight into currently used cloud solution pricing models, we studied pricing models of cloud offerings from 54 companies. Our analysis was carried out in September and October 2012 in the following steps: selecting cloud companies for the data sample; search for IaaS-, PaaS- and SaaS-offerings and their pricing information from their webpage; exclusion of those that provide a different type of service or do not provide enough pricing information; evaluation of SBIFT model iteratively. As a result, after searching for pricing data of offerings from more than 160 cloud providers, we could build up 73 pricing model from 54 firms by using the SBIFT model (see Table 1 for more details).

	IaaS	PaaS	SaaS	Total
Number of companies	7	14	33	54
Number of offerings	19	16	33	68
Number of pricing models	20	19	34	73

Table 1. Analyzed pricing models

Data sample selection: To ease the search of the cloud offerings, we identified our sample with the help of an internet portal Cloud Computing Showplace[1], that enlists more than 2050 cloud companies. In this online directory, cloud provider companies can register and categorize themselves into IaaS, PaaS and SaaS providers. SaaS providers can also categorize themselves by industry sector and application category.

We utilized this portal since it contains the most comprehensive collection of cloud providers compared to other portals (e.g. cloudservicemarket.info or www.saasdir.com) and the number of registered companies are growing continuously, fact that suggests that the directory is an up-to-date, maintained and used portal. To increase the reliability of our sample, we added additional validation steps into the process e.g. by excluding the non-cloud offerings.

We identified our data sample by choosing all registered IaaS and PaaS providers and one SaaS company with relevant pricing data from each industry sector. Since the number of registered SaaS companies is too large and growing constantly, we selected SaaS companies from each industry sector randomly until we had detailed pricing data of at least one SaaS offering from each industry sector in order to increase the industry coverage of the sample data.

[1] `http://cloudshowplace.com`

Review of the offerings and disclosure of pricing information: In order to increase the reliability of our data sample method, we reviewed the offerings and excluded the non-IaaS, non-PaaS and non-SaaS services, respectively. Concerning the disclosure of pricing information, our experience is in line with Lehmann et al. [20], who conducted an empirical study on the pricing models of SaaS providers registered on this portal. They found, that especially small and medium size firms provide pricing information on their website. Since not every aspect of the pricing model could be found in most cases, we agreed on excluding data from our sample where the companies did not provide enough information to understand the pricing logic as a whole.

Analysis of the SBIFT model: During our analysis, we matched each pricing model with a SBIFT pricing model pattern that can be defined as a combination of the positions of the pricing model characteristics along the SBIFT dimensions. While defining the positions, we selected the item that described the pricing characteristic in the most accurate way. The evaluation was done in an iterative process with the following evaluation criteria: (i) Each of the characteristics of the pricing model can be matched to a position of a dimension in the SBIFT model. (ii) One pricing pattern in the SBIFT model describes pricing models, that share the same characteristics. If the evaluation criteria was not met, we modified the SBIFT model to address the problems occurred and started a new iteration until the SBIFT model pattern could be defined for each sample data and the evaluation criteria was met.

4 Research findings

4.1 SBIFT model in cloud context

Based on our study, we propose some modifications to the SBIFT model that is specific to the cloud services industry (see Figure 2). The framework consists of 7 dimensions depicted in continuous scale, that describe the details of the offering. Next the proposed modifications are described compared to the SBIFT model.

Scope dimension: Our study revealed that identifying the level of bundling in the Scope dimension is challenging without some kind of categorization between the cases Attribute and Package. Based on the literature, we identify the categories *Package* as *Pure bundling* and *Attribute* as *Unbundling*. The combination of these is referred in the literature to as *Customized bundling*, where customers can choose the components of the bundle while the seller determines the price and scope of the bundle [21]. In IT industry, we see examples of customized bundling when even the price and the scope of the bundle is negotiable. To ease the process of determining the scope level, we propose the categories [Bundling where the amount of some items can be chosen from predefined options] and [Bundling where the amount of some items can be chosen freely].

Tiered pricing: We propose to add a new item to the Formula dimension for offerings with a fixed price and a limitation on the volume or the functionality, where the user has to switch to a less-limited offering with a different price if (s)he requests more volume or functionality. Named as *Tiered-pricing*, the formula attempts

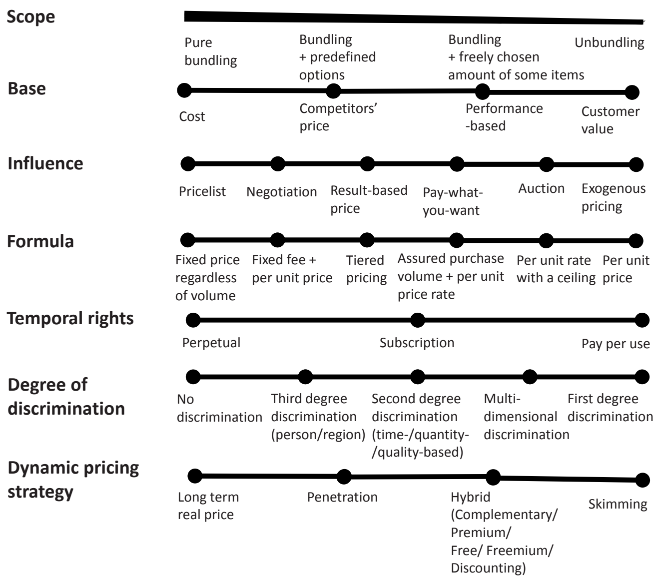


Fig. 2. Cloud Solution Pricing Framework

to package services and products by matching price levels to user's willingness-to-pay [14]. This formula is popular among IT offerings that apply vertical versioning.

Subscription-based pricing models: In the Temporal rights dimension of SBIFT model the authors distinguish between *Leasing*, *Renting* and *Subscription*. However, these three concepts are faded in cloud literature (see e.g. [17, 5]), therefore we propose to use the term Subscription meaning Renting and Leasing as well and leaving Renting and Leasing out of the framework as separate items.

Usage-based pricing models: In cloud literature, the term Pay per use pricing is used when the customer is charged on the actual usage, that has to be monitored and measured [22]. The customer does not have to make any commitment to use the service or product for a predefined period: there is no obligatory monthly fee, the user pays for the used volume. In digital content pricing literature, units represent a pricing metric that can be either linked to the actual usage or volume of the service/product (usage-dependent metric) or represent only the usage potential (usage-independent metric) [7, 20]. Hence, the term usage-based pricing known from cloud industry refers to a SBIFT price model, where the Formula dimension is Per unit price with a usage-based metric and the Temporal rights is Pay per use.

Performance-based pricing: Being a broadly used pricing strategy in integrated solution pricing, we propose to add the category *Performance-based pricing* to the Base dimension, that takes into consideration both the suppliers' costs and the customers' perceived value. In this case, the seller guarantees a certain performance level for a negotiated price and pays a penalty if this is not achieved [15, 23].

Proposed dimension: Degree of discrimination: Based on literature review and the wide use of this pricing aspect of our data sample, we propose to add the dimension Degree of discrimination to the SBIFT model. Price discrimination is used when the same product/service is offered for different buyers for different price. This strategy is extremely important for providers of digital goods, since the low marginal costs allow them to sell the offering also for customers with low willingness to pay [7]. The categories of the dimension are proposed as follows.

The left most item is *No discrimination*, meaning that the product/service is offered for the same price for everybody. In case of *First degree discrimination* the vendor offers the same product/service with different prices for different customers. *Second degree price discrimination* is used when providers sell different units of output for different prices [24]. In this case, customers use self-selection to choose from the offers [25]. Second degree price differentiations can be quantity-, time- and quality-based [7]. In case of *Quantity-based price discrimination* the price depends on the amount of the bought goods [24]. When prices differ in different points of times, *time-based price discrimination* is used. In case of *Quality-based price discrimination* different product/service variants are offered with different price [26]. When applying *Third degree price discrimination*, the vendor identifies different customer groups based on their willingness-to-pay [26]. Third degree price discrimination can be Personal (e.g. student discounts) or Regional (e.g. different prices for developing countries) [7]. *Multi-dimensional price discrimination* occurs when price differentiation is made based on more than one dimension [7].

Proposed dimension: Dynamic Pricing Strategy: Because of its important role in cloud pricing suggested by the literature [7], we propose Dynamic Pricing Strategy to the SBIFT model. Prices set in a dynamic environment can influence the demand behavior of price sensitive customers [27]. Dynamic pricing is the strategy where prices are not fixed for a relatively long period, but the seller dynamically changes the prices over time, based on factors such as time of sale, demand information and supply availability. Next the categories of the dimension are proposed.

The first option is the *Long-term real price* strategy, when prices are kept the same for longer periods and they are adjusted only if necessary, not as a part of a predetermined strategy. The next option is the *Penetration strategy*, when vendors use low prices for faster market-entry and then increase prices over time [28, 12]. In case of *Skimming* the vendor sets high prices in the early stages of market development and then gradually reduces the prices to attract also more price sensitive market segments [12]. *Hybrid pricing strategies* [14] combine elements of penetration and skimming strategies and may contain for example: *Complementary pricing* [14], *Premium pricing* [14], *Free* [8], *Freemium/Follow-the-free* [8, 7] or *Random or periodic discounting* [14].

4.2 Pricing models in cloud industry

Our analysis shows, that indeed, currently used pricing models are very complex, difficult to understand and compare (in line with [8, 29]). Solutions appear as a result of co-operation and competition between the actors of the ecosystem, and the interconnectivity between the actors is visible also in the pricing models (in line with [30]). In Figure 3, currently used pricing model characteristics of different service sectors are marked, where the values inside the rectangles describe the rounded usage proportions of the respective pricing aspect. In the picture the most popular pricing patterns and the most rarely used categories are also shown. Results related to the dimensions *Base* and *Dynamic pricing strategies* are missing from the figure, since there was not enough data regarding these two aspects. It can be seen from the figure, that firms use similar pricing models for IaaS, Paas and SaaS offerings.

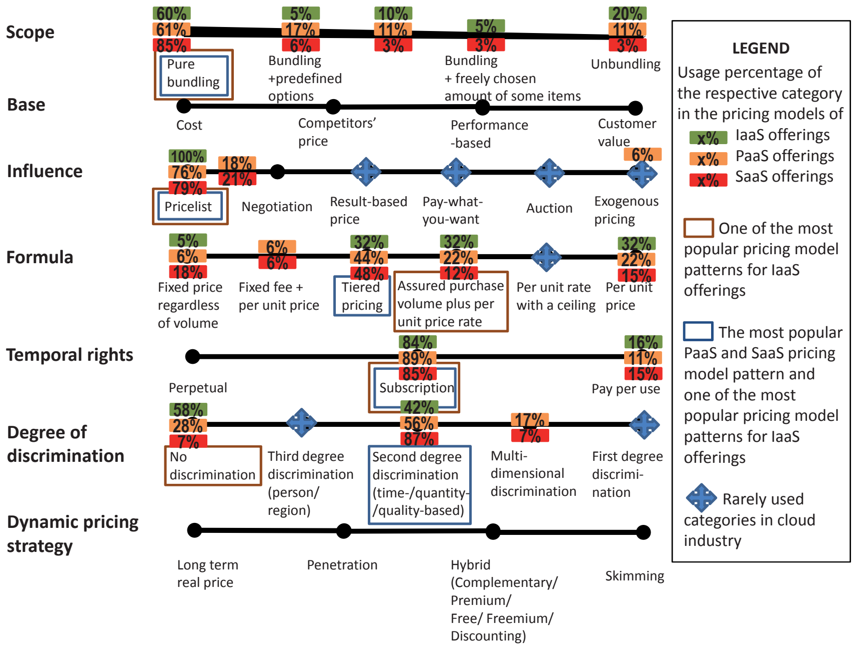


Fig. 3. Currently used pricing models in the cloud industry

Most popular pricing model patterns

Based on our analysis, we can conclude that cloud providers indeed differentiate by price since there is a big diversity in applied pricing models. The most popular pricing model is *[Pure bundling, Pricelist, Tiered pricing, Subscription and Second degree discrimination]* for all IaaS, PaaS and SaaS offerings, being applied in more than 20% of the cases. Price bundling is an effective pricing strategy if variable costs are near zero, or at least relatively low compared to the customers' willingness to pay. On the other hand, using different price bundling and unbundling solutions result in a nontransparent market because of the difficulties in price comparisons, and that effects negatively both the providers and the customers [29]. Pricelists are broadly used in cloud industry, especially when there is a large customer base with similar needs. The preference of Subscription over Pay per use is revealed also in other research work (e.g. [20]). Customers and providers prefer estimable budget and no transaction costs of usage monitoring and billing, even though the risk of under- and overestimation of resource needs has to be paid by a party from the value chain. Customers are open for price discrimination [31] and prefer to use self-selection to choose from the offerings. Second degree discrimination is often used together with Tiered pricing, where providers don't deal with billing extra units separately.

In case of IaaS offerings, another popular pricing model is revealed since IaaS offerings are priced in 20% of the cases with the pricing model *[Pure bundling, Pricelist, Assured purchase volume plus per unit price, Subscription and No discrimination]*. As a difference to the price model above, customers get the same product for the same price without any discrimination, and they have the option to buy additional resources with a predefined unit price.

Our study revealed also, that *Free trial version* is offered to the users in 10%, 90%, and 56% of IaaS, PaaS and SaaS offerings, respectively. Besides this hybrid strategy, we met examples of *Tiered marginal discounting*, which assures that usage increase is not so painful while usage decrease still brings economic benefits for the customer.

Rarely used categories

Despite of the big diversity in cloud pricing, there are still rarely used categories that may provide differentiation for firms. Based on our findings, one of the rarely used categories is *Result-based pricing*. However, this category may be often used among business partners, where the actors of the value chain split the generated revenue. Examples of rarely used *Pay-what-you-want* pricing are the popular games downloadable from Humble Bundle website[2] [32]. *Auction pricing* is also rarely used, however, a good example from IaaS industry could be Amazon's pricing model regarding the EC2 Spot Instances. On the other hand, Shapiro and Varian [33] state that auctions is usually not a viable option for digital goods where the incremental cost of production is zero. Examples of *Exogenous pricing* are found -however rarely- in SaaS pricing: solutions are priced partly based on the pricing model of IaaS provider - in this case, neither the SaaS provider nor the customer have an influence on this price component. No examples have been found by the authors for the use of *Per unit rate with a ceiling* in cloud industry. Our study reveals, that *Third degree discrimination* is not used alone, but it is preferred to be applied together with *Second degree discrimination*. In addition, *First degree discrimination* is rarely used in cloud context, probably because providers have difficulties in acquiring knowledge on each user's willingness-to-pay [7].

5 Conclusions and further research

Pricing is a strategic tool in managers hands, where finding a good price model brings success for the companies. On the other hand, it is a challenging task with long-term consequences, where decision makers have to take into consideration many factors, such as the offering itself, the target market segment with specific customer needs, the competitors' similar offerings, the costs, etc. With the sudden growth of different cloud

[2] http://www.humblebundle.com/

solutions, also pricing has become increasingly complex resulting in a ”constantly changing labyrinth” of pricing [8]. In this research, we attempted to find a systematic way to describe the pricing models in order to help decision makers plan, develop and speak about pricing alternatives. The proposed 7-dimensional model is an extended and customized version of the SBIFT model developed for cloud industry, that takes into consideration both the general knowledge about pricing and the specific cloud characteristics.

In this paper, an empirical study has been carried out in order to identify the currently used pricing models of the cloud solutions. We found, that the pricing models of IaaS, PaaS and SaaS offerings have similar patterns, that leads us not to distinguish between different service categories but rather concentrate on pricing of cloud solutions. In line with Kihal et al. [29] and Cusumano [8], we found out also, that the big diversity in the pricing models makes price comparison difficult.

Our study has some limitations that provide avenues for further research. Besides our analysis of pricing information available online, data has to be gathered and studied from other sources as well, e.g. through cases studies or quantitative research. In further research, dependencies between the dimensions and categories have to be studied also. The interaction between different actors of an ecosystem has an impact also on pricing. Offerings are interconnected and pricing models have to be established in a complex service system with multiple stake-holders [30]. Further work is needed to analyze how the pricing models of different actors enable or limit each other's pricing models [11].

References

1. Weinhardt, C., Anandasivam, A., Blau, B., Borissov, N., Meinl, T., Michalk, W., Stößer, J.: Cloud computing–a classification, business models, and research directions. Business & Information Systems Engineering **1**(5) (2009) 391–399
2. Anandasivam, A., Premm, M.: Bid price control and dynamic pricing in clouds. In: Proceedings of the European Conference on Information Systems. (2009) 1–14
3. Piercy, N.F., Cravens, D.W., Lane, N.: Thinking strategically about pricing decisions. Journal of Business Strategy **31**(5) (2010) 38–48
4. Gourville, J., Soman, D.: Pricing and the psychology of consumption. Harvard Business Review **80**(9) (2002) 90–105
5. Ojala, A.: Software renting in the era of cloud computing. In: Cloud Computing (CLOUD), 2012 IEEE 5th International Conference on, IEEE (2012) 662–669
6. Porter, M.: Competitive strategy: Techniques for analyzing industry and competitors. Competitive strategy: techniques for analyzing industry and competitors (1980)
7. Lehmann, S., Buxmann, P.: Pricing strategies of software vendors. Business & Information Systems Engineering **1**(6) (2009) 452–462
8. Cusumano, M.A.: The changing labyrinth of software pricing. Commun.ACM **50**(7) (jul 2007) 19–22
9. Schramm, T., Wright, J., Seng, D., Jones, D.: Six questions every supply chain executive should ask about cloud computing. Accenture Institute for High Performance (2010)
10. Hinterhuber, A.: Towards value-based pricingan integrative framework for decision making. Industrial Marketing Management **33**(8) (2004) 765 – 778

11. Iveroth, E., Westelius, A., Petri, C.J., Olve, N.G., Coster, M., Nilsson, F.: How to differentiate by price: Proposal for a five-dimensional model. European Management Journal (2012)
12. Shipley, D., Jobber, D.: Integrative pricing via the pricing wheel. Industrial Marketing Management **30**(3) (2001) 301 – 314
13. Danziger, S., Israeli, A., Bekerman, M.: The relative role of strategic assets in determining customer perceptions of hotel room price. International Journal of Hospitality Management **25**(1) (2006) 129–145
14. Harmon, R., Demirkan, H., Hefley, B., Auseklis, N.: Pricing strategies for information technology services: A value-based approach. In: System Sciences, 2009. HICSS '09. 42nd Hawaii International Conference on. (2009) 1–10 ID: 1.
15. Bonnemeier, S., Burianek, F., Reichwald, R.: Revenue models for integrated customer solutions: Concept and organizational implementation. Journal of Revenue & Pricing Management **9**(3) (2010) 228–238
16. Sundararajan, A.: Nonlinear pricing of information goods. Management Science **50**(12) (Dec. 2004) pp. 1660–1673
17. Ojala, A.: Revenue models in saas. IT Professional (2012)
18. Ferrante, D.: Software licensing models: What's out there? IT Professional **8**(6) (2006) 24–29
19. Choudhary, V.: Comparison of software quality under perpetual licensing and software as a service. J. Manage. Inf. Syst. **24**(2) (October 2007) 141–165
20. Lehmann, S., Draisbach, T., Buxmann, P., Dörsam, P.: Pricing of software as a service–an empirical study in view of the economics of information theory. Software Business (2012) 1–14
21. Hitt, L., Chen, P.: Bundling with customer self-selection: A simple approach to bundling low-marginal-cost goods. Management Science (2005) 1481–1493
22. Armbrust, M., Fox, A., Griffith, R., Joseph, A., Katz, R., Konwinski, A., Lee, G., Patterson, D., Rabkin, A., Stoica, I., et al.: A view of cloud computing. Communications of the ACM **53**(4) (2010) 50–58
23. Becker, M., Borrisov, N., Deora, V., Rana, O.F., Neumann, D.: Using k-pricing for penalty calculation in grid market. In: Hawaii International Conference on System Sciences, Proceedings of the 41st Annual. (2008) 97–97 ID: 1.
24. Varian, H.: Differential pricing and efficiency. First Monday **1**(2-5) (1996)
25. Spiegel, Y.: Second degree price discrimination. Tel Aviv University (1997)
26. Varian, H.: Versioning information goods. University of California, Berkeley (1997)
27. Anandasivam, A., Buschek, S., Buyya, R.: A heuristic approach for capacity control in clouds. In: Commerce and Enterprise Computing, 2009. CEC'09. IEEE Conference on, Ieee (2009) 90–97
28. Dean, J.: Pricing pioneering products. The Journal of Industrial Economics (1969) 165–179
29. El Kihal, S., Schlereth, C., Skiera, B.: Price comparision for infrastructure-as-a-service
30. Ng, I.C.L.: The future of pricing and revenue models. Journal of Revenue & Pricing Management **9**(3) (2010) 276–281
31. Anandasivam, A., Best, P., See, S.: Customers' preferences for infrastructure cloud services. In: Commerce and Enterprise Computing (CEC), 2010 IEEE 12th Conference on. (nov. 2010) 144 –149
32. Jurisic, M., Kermek, D.: Taxonomy of digital economy business models. In: MIPRO, 2011 Proceedings of the 34th International Convention, IEEE (2011) 1414–1419
33. Shapiro, C., Varian, H.: Information rules: a strategic guide to the network economy. Harvard Business Press (1998)

II

SAAS ARCHITECTURE AND PRICING MODELS

by

Gabriella Laatikainen & Arto Ojala, 2014

Proceedings of IEEE SCC 2014, pp. 597-604

SaaS architecture and pricing models

Gabriella Laatikainen and Arto Ojala
Department of Computer Science and Information Systems
University of Jyväskylä
Jyväskylä, Finland
{gabriella.laatikainen, arto.k.ojala}@jyu.fi

***Abstract*— In the new era of computing, SaaS software with different architectural characteristics might be priced in different ways. Even though both pricing and architectural characteristics are responsible for the success of the offering; the relationship between architectural and pricing characteristics has not been studied before. The present study fills this gap by employing a multi-case research. The findings accentuate that flexible and well-designed architecture enables different pricing models; however, poorly designed architecture limits also the pricing. Scalability and high level of modularity are the major enablers of a great variety of pricing models. Using public cloud services may lead to introducing usage-based pricing or in the contrary, making the pricing simpler. Applying multi-tenancy lowers the customizability, consequently the customers' negotiation power decreases. Pricing may give special requirements to the architectural design, such as scalability, customizability and additional components.**

Keywords- cloud; pricing; SaaS; SaaS architecture

I. INTRODUCTION

Software-as-a-Service (SaaS) is both a delivery and business model defined by software architectural and business model characteristics. Recent literature describes SaaS as a multi-tenant, virtual, scalable and configurable application that is accessible through browser [1]–[4]. On the other hand, the SaaS model is understood as offered through a different revenue logic compared to the traditional licensed software, such as subscription-based and/or usage based pricing [2], [5]–[7].

The emerging diversity of SaaS pricing models [8] has an impact on the product development; including technical architecture and product design. While traditional software products might be priced at the final stage of the product development, pricing of SaaS has to be considered at the early design phase [9]. Consider the example of Google ad-financed pricing model. In this case, integration of advertisements into the software's front-end has to be designed early enough to allow monetarization. More common examples include incorporating usage measurement into the software because of the usage-dependent pricing units.

Besides the impact of pricing on the architecture, in some cases, the software architecture is responsible for limiting or enabling the use of different pricing model alternatives. For example, if the users' resource usage is difficult to estimate (e.g. the architecture does not have proper logging or there is no clear usage pattern), then the company might perform financially better with a usage-based pricing model, even though the sales department prefers fixed monthly fee (since customers wish to have an estimable budget). Thus, architecture and pricing are interrelated and the success depends also on the harmony between the software architecture and pricing model.

The interrelation of architectural and pricing characteristics has an impact also on the product development and management processes. To date, architectural decisions are usually made by technical staff of the company (architects and developers), while pricing related decisions belong to the responsibilities of business managers (product managers, product line managers, directors, sales managers, etc.) [9]. In many cases, these two units of the company do not interact with each other on daily basis; thus, the unsuitability of the software's pricing model and architecture might come to light too late causing avoidable losses. Hence, in cases when the software's architecture and its pricing are closely related, the knowledge of these interrelations is vital for both the technical lead and the business managers of the company.

Surprisingly, the connection between architectural and pricing characteristics of SaaS software has not been studied before. To fill this gap, the aim of this research is to understand the impact the architecture and pricing models have on each other. As a result of a multi-case study of 5 companies, we aim to answer the following research questions: (1) How does software architecture enable and limit pricing models? and (2) What is the impact of pricing on the software architecture?

The contribution of the research is two-fold. First, the research proposes a theoretical model that describes the relationship between software architecture and its pricing models. Secondly, the managerial implications provide insights into (1) what technical details are important in decision making about pricing and (2) what pricing aspects may have an impact on the architectural decisions.

The structure of this article is as follows. In the next section, we give an overview on recent work related to SaaS architecture and cloud pricing. In Section III, we describe the research methodology used in this article. In Section IV we present the findings of our research. We conclude our paper with a summary and discussion in Section V.

II. LITERATURE REVIEW

In this section, first the current literature on cloud computing and SaaS architecture is presented. Thereafter, recent work on cloud maturity models is summarized. Then, the parameters of cloud pricing models are described. At the end of the section, the findings and the motivation for this article are discussed.

A. Cloud computing and SaaS architecture

Cloud computing provides access to computing resources, storage space, and software applications via internet as a service. Cloud computing can be divided roughly into three service layers. These consist of (i) Infrastructure as a Service (IaaS), which provides computation and storage capacity, (ii) Platform as a Service (PaaS), which provides software development tools and an application execution environment, and (iii) Software as a Service (SaaS), which provides applications on top of PaaS and IaaS [10], [11].

The SaaS model evolved from Application Service Provisioning (ASP) in the late 1990s [4], [12]. ASP was developed as an alternative to on-premise software. It offered the possibility for clients to outsource the hosting and maintenance of the software to an ASP vendor [4]. The ASP model was based on a single-tenant architecture in which each customer had a customized version of the software in the ASP provider's server [13].

SaaS architecture is similar to service-oriented architecture [2], [13]. SaaS is a delivery model, software that is available through the network. Marston et al. reported virtualization (presenting an abstract, emulated computing platform to the users instead of the physical characteristics), multi-tenancy (a single instance of an application software serves multiple clients) and web service (communication over the HTTP protocol) as core architectural characteristics of SaaS software [1]. A well-defined SaaS architecture should be configurable (the application's appearance and behavior can be altered by the users), multi-tenant and scalable (maximized concurrency, effective use of application resources) [2].

As a key characteristic, multi-tenancy is a requirement for a SaaS vendor to be successful [14]. In a multitenant architecture, a single instance of common code and data is shared between multiple tenants [15]. Besides the requirements of shared hardware resources, shared application and shared database instance, Bezemer et al. requires also high degree of configurability in look-and-feel and workflow from multitenant software [16]. Some researchers consider also multi-instancy as a form of multi-tenancy [14], where vendors host separate instances for each customer within shared hardware [13], [14].

Multi-tenancy has many advantages. First of all, it improves the utilization rate of hardware resources and it eases the deployment and maintenance of the software. It also opens new data aggregation opportunities. These benefits result in lower maintenance costs that allow the provider to target also small and medium-size enterprises and thus to catch the "long tail" of the market. [2], [15], [16]

On the other hand, there are also disadvantages of multi-tenancy. Since the tenants share hardware resources, a problem caused by one of the tenants have an impact also on other tenants. Sharing the same database also increases the importance of scalability, security and zero-downtime requirements. Because of increased configurability and thus more complex code, the development work might require more efforts than in case of single-tenant application [16]. Multi-tenant architecture does not allow high customization, since customer-specific configurations can only be made at the meta-data layer [17].

B. SaaS software maturity

Some research groups suggest that a mature SaaS model can be achieved in an incremental way, and the maturity level of SaaS software depends on the level of SaaS architectural characteristics [2], [13] or architectural and business characteristics [18], [19]. Regarding the architectural properties, these maturity models consider multi-instance, customer-specific ASP architectures as the least cloud mature architectures and they call scalable, configurable, and multi-tenant-efficient applications as the most mature ones [2], [13]. However, different components can be at different maturity level. In the cloud maturity model of Kang et al., 16 different maturity levels are identified along Service Component and Maturity Level axes [19]. Besides the Data, System and Service components, the Business characteristics are also taken into account in this model. In Forrester's maturity model, 6 levels are identified that considers also the firm strategy as a key factor in cloud maturity. In this model, outsourcing resides at the lowest level, while firms at the most mature level offer dynamic business applications as a service [18].

Other research groups focus on classifying the SaaS providers into different business archetypes, such as "pure-SaaS" and "enterprise-SaaS" [20], [21]. Pure SaaS refers to software that is simple to use and has low or no requirements for customization [22]. According to Benlian et al., pure-SaaS products also have lower strategic significance in a customer's business processes compared to enterprise-SaaS products [20]. In addition, pure-SaaS products, such as office systems, may have lower inimitability [20]. Enterprise-SaaS, on the other hand, refers to software which is more complex and which may require support, involving integration with customers' existing IT systems [22]. According to Benlian et al. enterprise-SaaS, such as ERP systems, has high strategic value for customers, and inimitability is high [20]. They also found that the adoption of enterprise-SaaS has a high level of uncertainty. As a third group, Luoma et al. introduced the notion of a self-service SaaS archetype, which presents highly standardized applications with easy adoption [22]. In self-service SaaS, customers themselves find applications from the Internet, and evaluate and deploy the software. These applications are mainly targeted at individual consumers [22]. Berman et al. reveal three business archetypes representing the extent to which organizations use cloud computing: "Optimizers" use the technology to enhance the value proposition and improve efficiency, "Innovators" create new streams of revenues or even change their role in the value network, and “Disruptors” may generate totally new customer needs and segments, possibly even new value chains [23].

As a summary, SaaS application cannot be classified in a discrete number of maturity types. The researchers accentuate that targeting the highest maturity level is not necessarily the best fit for every vendor. Software vendors should decide the service components that are shared across the customers and also the level at which these components are shared. Decision makers should take into account many factors, such as the business needs, the targeted customers, architectural characteristics, financial and operational considerations. In some cases, entering a higher level of SaaS maturity is not possible because of confidentiality and security aspects, or since customers may have legal or cultural resistance to multi-tenancy. Some applications can't be moved because the migration is not beneficial cost-wise or the nature of the product/ service requires isolated data and code. In some cases, it may be difficult to guarantee the SLA obligations (e.g. downtime, support options, disaster recovery).

C. Pricing models

SaaS software may be priced in many different ways. Even though one of the key conditions for commercial success of cloud services is the clearness and transparency of pricing for both customers and providers [3], [24], SaaS price models are very diverse and complex [8]. In software industry the most common revenue streams are: i) monthly or annual subscription fees, ii) advertising based revenue, iii) transaction based revenue (customers are charged based on the number of transactions they perform), iv) premium based revenue (revenue is generated from charging for premium versions besides the free versions), v) revenue from implementation and maintenance services and vi) software licensing [25]–[28].

Software pricing in these above introduced revenue models may base on different aspects. The software pricing model parameters of Lehmann and Buxmann [29] and the SBIFT model of Iveroth et al. [30] are taken into account in the classification of cloud pricing models that describes these models along 7 dimensions [31]:

1. *Scope* represents the granularity of the offering, whether it is priced as a package or different prices are given for different functionalities.
2. *Base* represents the information base the price is set on. The price might be decided based on cost considerations, the competitors' prices, based on performance or customer value.
3. *Influence* represents the ability of buyers and sellers to influence the price, and it contains the options Pricelist, Negotiation, Result-based price, Pay-what-you-want, Auction and Exogenous pricing.
4. *Formula* represents the connection between price and volume, and it contains different variations of fix and variable price components.
5. *Temporal rights* represent the length of service's usage period, and it can be Perpetual, Subscription-based or Pay-per-use.
6. *Degree of discrimination* represents the level of price variety depending on the buyer. The product or service may be priced differently for different regions, for different time of buying. The price can depend on the acquired volume or the quality, or it might be even customer-specific.
7. *Dynamic pricing strategy* represents the strategy of dynamic price change over time. Penetration, skimming or hybrid pricing strategies belong to this dimension.

D. Summary

In summary, well-designed SaaS architecture requires virtualization, multi-tenancy, web service, scalability and configurability. Cloud pricing characteristics include scope, base, influence, formula, temporal rights, degree of discrimination and dynamic pricing strategies. Choosing the right maturity level requires architectural, business and operational considerations. Even though researchers paid increasing attention to both SaaS architecture and pricing models, there is no research paper focusing on the relationship between software architecture and pricing models.

III. Methodology

The aim of the research is to enable an in-depth investigation of a complex phenomenon in a real-life environment, where architectural and pricing decisions are made. Since the study aimed to understand the behavior of a firm rather than quantitative measurement, the case study method is suitable for this purpose [32], [33]. The research setting for the study consists of five software firms marked with A-E (see Table I). In order to gain a deep understanding on the phenomena, the following multiple criteria is used to select the cases: (i) the case firms develop software for different industries; (ii) the sample includes both recently established and relatively old firms; (iii) the sample includes both traditional software firms and SaaS companies; (iv) the sample includes SaaS with different cloud maturity level; (v) researchers have good access to the required information, as recommended by [34].

TABLE I
OVERVIEW OF THE CASE FIRMS

Firm	Year of establishment	Number of employees	Target industry
A	1997	cca. 980	Finance, public sector, telecom and other industries
B	1998	30	Telecom operators, Component manufacturers and service providers for telecom networks
C	2011	3	Public and private sector
D	2008	12	Large and medium sized corporations
E	2006	30	Furniture chains and furniture manufacturers

Multiple sources are used to gather data on each case firm. The data is collected primarily through semi-structured interviews with multiple decision makers of the case companies. In TABLE II, the number of interviews is presented with representatives of the case firms. The interviewees consist of Chief Executive Officers, vice presidents, sales managers, architects, technical leads and project managers. The interviews last cca. 60 minutes and they are all recorded and transcribed. Thereafter, the complete transcripts are sent back to the interviewees for review. Some of them commented on the content while other interviewees accepted the transcripts as they were. In addition to face-to-face meetings, information is gathered through phone calls and emails. Besides these, secondary information is gathered about the cases through web pages, brochures and press releases.

TABLE II
NUMBER OF INTERVIEWS

Firm	A	B	C	D	E
Nr. of interviews	1	8	4	6	8

We utilized content analysis as the data analysis method. The case data analysis consisted of three concurrent flows of activity [35]: (i) data reduction, (ii) data displays and (iii) conclusion-drawing/verification. In (i) data reduction phase, the data were given focus and simplified through compilation of a detailed case history of each firm. This is in line with Pettigrew [36], who suggests that organizing incoherent aspects in chronological order is an important step in understanding the casual links between events. Thereafter, on the basis of interviews and other material collected from the case firms, we used tables to identify and categorize the unique patterns of each case under subtopics derived from the research questions. In addition, we used checklists and event listings to identify critical factors related to the phenomena encountered [35]. In (ii) the data display phase, we arranged the relevant data drawn from the findings of the earlier phase into new tables. In (iii) the conclusion drawing and verification phase first we concentrated on identifying the aspects that appeared to have significance for this study. At this stage we noticed regularities, patterns, explanations and causalities related to the phenomena. After conclusion drawing, we verified the results and carried out discussions in order to avoid misunderstandings. In the last stage of the research, we sent the manuscript to the representatives of each firm for review.

IV. FINDINGS

A. *Overview of the case firms and relationship between architecture and pricing*

In TABLE III, we provide a short overview of the case firms regarding the software architecture and pricing model of their main product or service. It can be seen from the table, that the companies are very different in terms of cloud maturity. However, subscription-based pricing is a common pricing model that is applied by each case firm.

TABLE III
ARCHITECTURE AND PRICING MODEL - OVERVIEW

Firm	Product/Service	Architecture	Pricing model
A	Development tool and Backend As A Service	Traditional software and PaaS. Use of public cloud services.	Premium pricing model (traditional software) and subscriptions with usage based pricing (PaaS)
B	Planning and optimization software for telecom operators	ASP architecture by design. No public cloud provider is used. Virtualization, scalability, high level of modularity.	Offered (i) traditionally, (ii) through subscriptions and (iii) as part of consultancy services
C	Software for user guides, commercials and media description	mobile web application, ASP architecture	One-time fixed fee and monthly subscription fee
D	Entitlement management software	SaaS, Service Oriented Architecture	Offered both with traditional licenses and subscriptions
E	Interactive 3D sales software	Designed as an ASP software. Migration to SaaS architecture is in progress.	One-time fixed fee, monthly subscription fee and usage-dependent hosting fee

In TABLE IV, the relationship between architecture and pricing is presented. The first two columns refer to the first research question regarding the impact of architecture on pricing models. In the last column, the effect of pricing on the architecture is presented. It can be seen from the table that the relationship between architecture and pricing varies case by case.

TABLE IV
RELATIONSHIP BETWEEN ARCHITECTURE AND PRICING

Firm	Architecture enables pricing models	Architecture limits pricing models	Pricing affects architecture
A	Flexible and configurable architecture enables different pricing models. Use of public cloud provider's services implies introducing usage-based pricing.	Traditional desktop application can't be migrated to SaaS and offered through subscription.	Fixed priced projects lead to poorer design. Pricing requires extra components. Creating premium functionalities on top of open source software implies use of specific technologies.
B	Scalable and highly modularized architecture enables different pricing models (subscription-based model, licenses, different bundling options, usage-based pricing).	Well-designed architecture does not limit the pricing.	Pricing requires scalable and customizable architecture, use of public cloud resources, different delivery modes and additional components.

C	Loose connection between architecture and pricing (startup firm)	Loose connection between architecture and pricing (startup)	Pricing will entail automatic billing tools and other configuration tools.
D	Loose connection between architecture and pricing (small firm focusing only on software development).	The architecture does not limit pricing, but gives the criteria on how to price.	Pricing does not affect architecture (small firm focusing only on software development).
E	Migration to SaaS architecture and use of public cloud services implies fixed price instead of usage-based pricing. Change in architecture enables change in pricing. Introducing SaaS architecture lowers the prices.	Multi-tenancy lowers the customizability, the product/service becomes more standardized; therefore the firm is less willing to negotiate with customers.	Usage-based pricing requires functionalities that enable pricing. Prices have to be lowered, therefore maintenance costs have to be decreased; thus, introducing SaaS architecture is needed.

Architecture and pricing are closely related in case of firms A and E, where the firms migrate their software to public cloud resources. For the case firm A, introducing a new PaaS service with usage based pricing model is under progress. Likewise, the case firm E currently migrates its product to SaaS architecture, and as a consequence, the pricing model becomes simpler and prices will be lowered. Representatives of case firms A and E affirmed that both architecture and pricing characteristics are considered in decisions related to pricing and technical details. Pricing and architecture are interrelated also at the firm B, where well-designed architecture enables many different pricing models. In return, these pricing models require high quality software. However, it is difficult to say, has the architecture impact on pricing or the other way around:

"Architecture affects pricing, pricing affects architecture … it is the egg-chicken problem … architecture and pricing are in symbiosis."

Conversely, the relationship is loose in case of firms C and D. Firm C is a startup company of 3 employees, where neither the architecture nor the pricing is yet mature; currently the firm's main goal is to attract new customers and get references. The simplicity of both the architecture and pricing model does not allow close relationship between architecture and pricing. The firm concentrates on short-term goals like working software and appropriate pricing for the customers, where architecture and pricing are independent from each other.

Likewise, firm D is a small company consisting of only 8 employees. The firm's main activity is software development, while the channel partners are responsible for end customer service, helpdesk support and pricing. Firm D is not involved in pricing issues regarding the end customers; thus, architecture and pricing do not interact in case of their software. One of the interviewees representing firm D stated:

"Pricing has no impact on architecture. The architecture does not limit the pricing, but it gives the criteria to find the right price level. If I would give the price level first, and then the development costs should match this level, it wouldn't be good."

B. How does software architecture enable and limit pricing models?

The interviewees all agreed that flexible and well-designed architecture enables different pricing models; however, poorly designed architecture limits also the pricing. A representative of company A accentuates the flexibility and configurability as key architectural characteristics that enable different pricing models.

"In this case architecture does not limit pricing. It is a very flexible architecture that enables configurability.[…] Having a cloud offering enables us to have monthly fees. Since the customer is closer to us, we know what he does and we are able to develop our service much more. Additional sales becomes easier."

Scalability and high level of modularity are the most important characteristics for company B that let them offer the same software with different pricing models.

"Architecture does not limit pricing, but enables it. Scalability and modularity enables many [pricing] possibilities."

"Architecture enables different models, such as SaaS and service packages, even licenses, everything is possible. If something happens and we can't estimate the users' resource needs then it would probably affect the pricing. Then probably we would apply usage-based pricing."

Using public cloud services may lead both to introducing usage-based pricing or getting rid of it and make the pricing simpler. In the first case, company A introduces the SaaS service as a new service and expects the customers to pay for the public resources based on their usage. However, company E sees the cloud providers' usage log data as an advantage since it enables the firm to simplify its pricing. Customers prefer simple pricing where they know the fee in advance. With the excessive logging and monitoring data, the company can estimate the customers' usage more easily.

However, software architecture limits pricing models as well. Company A offers its software as a desktop application that has to be installed on customers' machine. The license-based software is sold with a yearly fee per user. In addition to this software, the company wants to introduce a new cloud based service with subscription-based pricing model. Besides the monthly fees, the customers will pay for the used resources based on their usage.

A representative of company E mentioned that introducing SaaS architecture and multi-tenancy lowers the negotiation power of the customers. Customization is more challenging in a multi-tenant architecture and with the architectural change the strategy of the company moves from creating customized software towards offering standard software with configuration possibilities. This drawback of multi-tenancy has to be accepted for smaller maintenance costs in turn.

"This new architecture makes customization much more limited. At the moment we have different instances for different customers, so we can customize it much more. It is

challenging to decide where is the border line where we move, what kind of customizations we will be able to do."

In the future, the company wants customers to configure and maintain different part of the software themselves. The new architecture allows customers to configure the user interface and the business logic rules; they can create new users, new elements and maintain the old ones through a simple web interface. The goal of the company is to restrict the cost of customer-based maintenance work to zero. However, the low level of customers' influence on setting the price limits the pricing. As a result, the company's value proposition is communicated through a pricelist.

C. What is the impact of pricing on the SaaS architecture?

The representative of firm E stated that the need for great architectural changes comes from the sales department of the company. The architectural change is needed for two reasons. First of all, prices and therefore maintenance costs have to be lowered. The customers' higher expectations, the need of lower prices and the high competition place new demands on software architecture and development.

"If we ask from the sales persons, they want to lower the price in order to get more new customers. On the technology side the maintenance costs should be lowered. But the final pricing decisions come from the marketing and sales. [...] So yes, the pricing has an impact on the architecture: the starting price is smaller now, the maintenance and other costs have to be lowered as much as possible. Usually we have technical and sales persons and we think together about pricing."

Secondly, the company wants to extend its services to another large market with different pricing needs than the countries where the company operates now. In this new country customers want short contracts with no fix fee in the beginning. This requires architecture where new customers can benefit from the services without long installation and integration costs.

"Here everybody understands that the initial project work has to be paid. [...] But in this new market customers are used to have only monthly fees, no long contracts. [...] The starting fee is commitment that makes the sales work more difficult and slow. [...]There we can sell our software with monthly fee only, no fixed starting fee."

Although the cost of the planned architectural changes is very high, it is seen as a required investment that has long-term benefit for the company and the only possible way that allows the company to grow.

Pricing may give special requirements to the architectural design. In case of company B scalability, high customizability and the use of public cloud providers' resources were the most important requirements from the sales department towards the technical team. In this company the software was priced already in the requirements specification phase of the development life cycle; therefore the requirements for pricing were taken into account in the architectural design. This finding is in line with Choudhary's finding: in most of the cases the subscription-based licensing leads to higher architectural requirements and greater investment in product development and that implies higher software quality [5].

In case of companies A and C, change in pricing model may require additional components, such as different infrastructure, automatic billing or configuration tools. Thus, the technical team has to be consulted before implementing changes in pricing model to give work estimation.

Pricing models have an impact also on work prioritization. Interviewees of companies A and E discussed that in case usage-based pricing is introduced, first those functionalities have to be developed that enable usage-based pricing (company E) and those that generate more resource usage (company A).

V. CONCLUSIONS

SaaS is a multi-tenant, virtual, scalable and configurable web application [1]–[4] that is offered through subscription-based and/or usage based pricing [2], [5]–[7]. The interrelation of architectural and pricing characteristics implies that basic knowledge on the offering's architecture is required for pricing decisions and pricing also affects the architecture. In this paper we presented the results of our multi-case study on the relationship between architecture and pricing.

Findings in this study reveal that architecture and pricing are tightly related in cases where the firm's value proposition resides at high cloud maturity level and hosting is outsourced to a public cloud provider. In this case architecture is an important factor in pricing, while pricing gives special architectural requirements. However, in case of startup firms, or smaller companies that focus only on software development, architecture and pricing have no or limited impact on each other.

Concerning the first research question, we found that flexible and well-designed architecture enables different pricing models; however, poorly designed architecture limits also the pricing. Scalability and high level of modularity are important characteristics that enable a great variety of pricing models. The decision of using public cloud services requires redesigning the pricing model as well. In some cases, the use of public resources leads to introducing usage-based pricing, while in other cases the pricing model becomes even simpler. Introducing multi-tenancy lowers the customizability of the software; thus also the negotiation power of the customers decreases.

The relationship between SaaS architectural and pricing characteristics is visible in Figure 1. In the figure, only those architectural and pricing characteristics are visible that have an impact on each other based on the findings. For example, the Base, Degree of Discrimination and Dynamic Pricing Strategy pricing characteristics are not affected directly by the architectural decisions; thus, these dimensions might be more influenced by the strategic decisions of the company and do not depend on the software architecture. In the figure, solid arrows represent enabling relationship between architectural and pricing characteristics, while dashed arrows are used to show the limiting relationship.

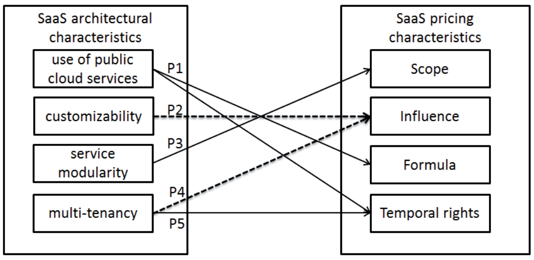


Figure 1. The impact of architecture on pricing models.

The relationships marked in the picture with P1-P5 can be described as follows:

P1. *Using public cloud services has an impact on both the Temporal rights and Formula dimensions.* For example in case of company A, introducing a new service that uses public cloud resources implies use of subscription-based pricing model (Temporal rights dimension) with usage-dependent pricing metrics (Formula dimension). Conversely, migration to public cloud at the company E makes the pricing simpler and the pricing model with usage-dependent pricing metrics is replaced with subscription-based revenue logic (Temporal rights and Formula dimensions).

P2. *The level of customizability has an impact on the possible influence of the customers on the pricing model (Influence dimension).* As an example, migration to a multi-tenant architecture lowered the level of customizability for case company E. This affects the pricing as well: standardization of the product/service leads to less negotiation.

P3. *High level of service modularization enables many different bundling options (Scope dimension).* For example, the company B's software is a scalable and highly modularized application that is offered through three different revenue model: traditionally, through subscription and as part of consultancy services.

P4. *Multi-tenancy limits the customizability level that may limit the negotiation power of the customer (Influence dimension).* For example in case of company E, the lower customizability implies less negotiation between the customers and the provider.

P5. *High level of multi-tenancy enables different options for the Temporal rights dimension of the pricing model.* For example, migration to multi-tenant architecture at the company E enables subscription-based revenue logic.

Concerning the second research question, pricing related decisions should be communicated early enough in the software development life cycle since pricing may give special requirements to the architectural design, such as scalability, high customizability and the use of public cloud providers' resources. This finding is in line with Choudhary's finding: in most of the cases the subscription-based licensing model leads to higher architectural requirements, thus, to greater investment in product development and that implies higher software quality [5]. Additionally, the findings reveal that if the pricing model changes, additional components may be required, such as different infrastructure, automatic billing or configuration tools. The pricing model has also an impact on the work prioritization.

The present study contributes also to the literature on understanding the business model changes due to migration from on premise to cloud services. We found that the use of cloud resources has an impact on the pricing model; namely, due to migration, the prices might be lowered and the pricing model might become simpler, or, usage-based pricing components might be introduced. Even though migration to cloud requires great investments, companies see this path the only way to survive under heavy competition in the market.

Due to the methodological circumstances, the findings of this study cannot be fully generalized. However, they can be used for further quantitative testing. Besides, the impact of pricing on the internal processes of the companies is also left for further studies.

References

[1] S. Marston, Z. Li, S. Bandyopadhyay, J. Zhang, and A. Ghalsasi, "Cloud computing—The business perspective," Decis. Support Syst., vol. 51, no. 1, pp. 176–189, 2011.

[2] F. Chong and G. Carraro, "Architecture strategies for catching the long tail," MSDN Libr. Microsoft Corp., pp. 9–10, 2006.

[3] C. Weinhardt, D.-I.-W. A. Anandasivam, B. Blau, D.-I. N. Borissov, D.-M. T. Meinl, D.-I.-W. W. Michalk, and J. Stößer, "Cloud computing–a classification, business models, and research directions," Bus. Inf. Syst. Eng., vol. 1, no. 5, pp. 391–399, 2009.

[4] A. Benlian and T. Hess, "Opportunities and risks of software-as-a-service: Findings from a survey of IT executives," Decis. Support Syst., vol. 52, no. 1, pp. 232–246, 2011.

[5] V. Choudhary, "Comparison of software quality under perpetual licensing and software as a service," J. Manag. Inf. Syst., vol. 24, no. 2, pp. 141–165, 2007.

[6] S. Stuckenberg, E. Fielt, and T. Loser, "The impact of software-as-a-service on business models of leading software vendors: experiences from three exploratory case studies," in Proceedings of the 15th Pacific Asia Conference on Information Systems (PACIS 2011), 2011.

[7] P. Tyrväinen and J. Selin, "How to sell SaaS: a model for main factors of marketing and selling software-as-a-service," in Software Business, Springer, 2011, pp. 2–16.

[8] M. A. Cusumano, "The changing labyrinth of software pricing," Commun. ACM, vol. 50, no. 7, pp. 19–22, 2007.

[9] H. B. Kittlaus and P. N. Clough, Software product management and pricing: Key success factors for software organizations. Springer, 2009.

[10] M. Armbrust, A. Fox, R. Griffith, A. D. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, and I. Stoica, "A view of cloud computing," Commun. ACM, vol. 53, no. 4, pp. 50–58, 2010.

[11] M. H. Hugos and D. Hulitzky, Business in the cloud: what every business needs to know about cloud computing. Wiley.com, 2010.

[12] M. Xin and N. Levina, "Software-as-a-service model: Elaborating client-side adoption factors," in Proceedings of

the 29th International Conference on Information Systems, R. Boland, M. Limayem, B. Pentland,(eds), Paris, France, 2008.

[13] J. Ju, Y. Wang, J. Fu, J. Wu, and Z. Lin, “Research on key technology in SaaS,” in Intelligent Computing and Cognitive Informatics (ICICCI), 2010 International Conference on, 2010, pp. 384–387.

[14] C. J. Guo, W. Sun, Y. Huang, Z. H. Wang, and B. Gao, “A framework for native multi-tenancy application development and management,” in E-Commerce Technology and the 4th IEEE International Conference on Enterprise Computing, E-Commerce, and E-Services, 2007. CEC/EEE 2007. The 9th IEEE International Conference on, 2007, pp. 551–558.

[15] C.-P. Bezemer and A. Zaidman, “Multi-tenant SaaS applications: maintenance dream or nightmare?,” in Proceedings of the Joint ERCIM Workshop on Software Evolution (EVOL) and International Workshop on Principles of Software Evolution (IWPSE), 2010, pp. 88–92.

[16] C.-P. Bezemer, A. Zaidman, B. Platzbeecker, T. Hurkmans, and A. t Hart, “Enabling multi-tenancy: An industrial experience report,” in Software Maintenance (ICSM), 2010 IEEE International Conference on, 2010, pp. 1–8.

[17] M. Cusumano, “Cloud computing and SaaS as new computing platforms,” Commun. ACM, vol. 53, no. 4, pp. 27–29, 2010.

[18] S. Ried, Forrester’s SaaS maturity model: Transforming vendor strategy while managing customer expectations (2008). .

[19] S. Kang, J. Myung, J. Yeon, S. Ha, T. Cho, J. Chung, and S. Lee, “A general maturity model and reference architecture for saas service,” in Database Systems for Advanced Applications, 2010, pp. 337–346.

[20] A. Benlian, T. Hess, and P. Buxmann, “Drivers of SaaS-adoption–an empirical study of different application types,” Bus. Inf. Syst. Eng., vol. 1, no. 5, pp. 357–369, 2009.

[21] K.-W. Huang and M. Wang, “Firm-Level Productivity Analysis for Software as a Service Companies,” ICIS 2009 Proceedings, 2009.

[22] E. Luoma, M. Rönkkö, and P. Tyrväinen, “Current Software-as-a-Service Business Models: Evidence from Finland,” in Software Business, Springer, 2012, pp. 181–194.

[23] S. J. Berman, L. Kesterson-Townes, A. Marshall, and R. Srivathsa, “How cloud computing enables process and business model innovation,” Strategy Leadersh., vol. 40, no. 4, pp. 27–35, 2012.

[24] A. Anandasivam and M. Premm, “Bid price control and dynamic pricing in clouds,” ECIS 2009 Proceedings, 2009.

[25] A. D’souza, J. Kabbedijk, D. Seo, S. Jansen, and S. Brinkkemper, “Software-As-A-Service: Implications For Business And Technology In Product Software Companies,” PACIS 2012 Proceedings, 2012.

[26] M. A. Cusumano, “The changing software business: Moving from products to services,” Computer, vol. 41, no. 1, pp. 20–27, 2008.

[27] A. Ojala, “Software renting in the era of cloud computing,” in Cloud Computing (CLOUD), 2012 IEEE 5th International Conference on, 2012, pp. 662–669.

[28] A. Ojala, “Software-as-a-Service Revenue Models,” IT Professional , vol.15, no.3, pp.54,59, 2013.

[29] S. Lehmann and P. Buxmann, “Pricing Strategies of Software Vendors,” Bus. Inf. Syst. Eng., vol. 1, no. 6, pp. 452–462, 2009.

[30] E. Iveroth, A. Westelius, C.-J. Petri, N.-G. Olve, M. Cöster, and F. Nilsson, “How to differentiate by price: Proposal for a five-dimensional model,” Eur. Manag. J., 2012.

[31] G. Laatikainen, A. Ojala, and O. Mazhelis, “Cloud Services Pricing Models,” in Software Business. From Physical Products to Software Services and Solutions, Springer, 2013, pp. 117–129.

[32] R. K. Yin, Case study research: Design and methods, vol. 5. Sage, 2003.

[33] G. Paré, “Investigating information systems with positivist case research,” Commun. Assoc. Inf. Syst., vol. 13, no. 1, p. 18, 2004.

[34] R. E. Stake, “The art of case study research,” Sage, 1995.

[35] M. B. Miles and A. M. Huberman, Qualitative data analysis: An expanded sourcebook. Sage, 1994.

[36] A. M. Pettigrew, “Longitudinal field research on change: theory and practice,” Organ. Sci., vol. 1, no. 3, pp. 267–292, 1990.

III

IMPACT OF CLOUD COMPUTING TECHNOLOGIES ON PRICING MODELS OF SOFTWARE FIRMS – INSIGHTS FROM FINLAND

by

Gabriella Laatikainen & Eetu Luoma, 2014

Proceedings of ICSOB 2014, pp. 243-257

Impact of Cloud Computing Technologies on Pricing Models of Software Firms – Insights from Finland

Gabriella Laatikainen and Eetu Luoma

Department of Computer Science and Information Systems,
University of Jyväskylä,
Jyväskylä, Finland
{gabriella.laatikainen,eetu.luoma}@jyu.fi

Abstract. In this paper we study the changes in the pricing models of software firms that use cloud computing technologies as part of their products and services. This paper presents findings from 324 responses to a questionnaire survey on how pricing model elements of software firms have changed as a result of adopting hardware virtualization, multi-tenancy, online delivery and configurability. The findings suggest that Software-as-a-Service firms – making use of the cloud computing technologies – are generally simplifying their pricing model, increasing the use of usage-based pricing, reducing the customers' influence and unifying their pricing across customers. These changes occur together with standardization of their products or services. The findings provide a view to the transformation of the software industry, characterized by both technological and business model redesigns.

Keywords: cloud, SaaS, pricing, software firms, business models.

1 Introduction

Software-as-a-Service (SaaS) is both a delivery and a business model for software firms defined by technological and business characteristics. Recent literature describes SaaS as the delivery of multi-tenant, virtual, web-based and configurable application that is accessible through browser [1]–[4]. Applying these technological characteristics to its application enables a software firm to offer a cloud computing service with the essential cloud characteristics to its customers. Viewing SaaS from the business perspective, the model is understood as offered through a different revenue logic compared to the traditional licensed software, such as subscription-based and/or usage based pricing [2], [5]–[7].

Introducing cloud technologies therefore implies changes not only to software architecture but also to business model design. Among the business model elements, a well-designed revenue logic is a key condition for commercial success. Pricing models influence not only the demand, but have an effect also on the way how users use the product or service, and have a long-term influence on customer relationships [8]. The revenue logic can also differentiate a product from the competitors and this way increase the company's revenues [9]. However, even though pricing is a powerful

C. Lassenius and K. Smolander (Eds.): ICSOB 2014, LNBIP 182, pp. 243–257, 2014.

strategic tool in manager's hands, it also causes challenges to software firms that develop SaaS to the market. Information is often difficult to price and the currently observed constantly changing labyrinth around software pricing makes pricing even more complex [3], [10]–[13].

With the emergence of cloud technologies, the software market evolves rapidly and the firms' needs for strategic changes increase. Different studies in current literature focus on software firms' revenue logic and their products and services. However, despite of its importance, there is a shortage of empirical evidence on how the software firms *changed* their pricing models due to adopting cloud computing technologies. This study fills the gap by analyzing 324 Finnish software firms to find out (1) what are the changes in pricing model that are caused by cloud computing technologies, such as virtualization, multi-tenancy, online delivery and configurability; and (2) whether changes in pricing model elements are caused directly by cloud computing technologies or through changes in the firms' products or services offered to their customers.

The contribution of this paper is two-fold. First, researchers gain a better understanding on how the cloud technologies transform the software industry and how firms change their value proposition and pricing model after adopting cloud technologies. Secondly, the managerial implications provide insights into how particular cloud technologies affect different aspects of pricing.

The structure of this article is as follows. In the next section, we give an overview on recent work related to value proposition and revenue logic as key business model elements in the context of cloud technologies and describe the hypotheses of this research. In Section 3, we describe the research methodology used in this article. In Section 4 we present the findings of our analysis. We conclude our paper with discussion and summary in sections 5 and 6, respectively.

2 Theoretical Background

2.1 Business Models

Business model is a conceptual model of a business: a description of how a company organizes itself, operates and creates value [10], [14]–[17]. The static view on business models sees them as a blueprint for the coherence between core business model components [18]. Besides others, the core business parameters include value proposition incorporating the product/service portfolio [14], [15], [18], [19] and revenue logic referring to the structure of income [14], [15], [19].

On the other hand, the dynamic view uses the business model concept as a tool to address change and innovation in the firm or in the model itself [18]. Changes in the model itself can be related to the different phases of the lifecycle of business models, such as creation, extension, revision and termination [20]. The reason for these changes might be a response to external and/or internal influences. In the literature, the advances in contemporary technology are argued to be a key external factor that leads to changes in business strategies and processes [17], [19], [21]–[24]. Moreover, Chesbrough and Rosenbloom [19] argue that the financial performance of a given firm is associated with developments in firm's environment, but *only* through changes in the firm's business model. Besides the external influences, the need for business model changes might also come internally. Business models are designed, implemented and changed by employees of the company who make decisions based on their perception of the firm's environment [18]–[20]. As a consequence, the elements of business models are interrelated and changes in one of the components might cause changes also in others [18].

There is currently little in the literature that empirically examines just how exactly software providers do convert to supplying SaaS. A couple of exceptions to this are the studies by Stuckenberg et al. [6], Ojala and Tyrväinen [25] and Novelli [26]. While their findings are based on rare cases, they both seem indicate a trend towards offering more standardized products and services, increasing customer-facing activities and changes in revenue logic towards subscription-based pricing.

2.2 Value Proposition and Cloud Technologies

As a core item of business model, value proposition communicates the value that the companies' product/service portfolio creates for the target customers using technology [19]. In software industry, the product/service portfolio incorporates the set of functionalities of the software, the needed infrastructure and the deployment, delivery and maintenance of the software [27], [28]. Specifically, software firms that develop SaaS to the market companies employ cloud technologies in their value proposition, such as hardware virtualization, multi-tenancy, and web service [1]. Besides, a cloud mature application should also be configurable [2]. These four technologies give the software firms the means to introduce SaaS service to the market, a service which has the essential cloud computing characteristics of on-demand self-service (through configurability), network access (web service), resource pooling (virtualization and multitenancy) and elasticity (virtualization), as they're described in the reference definition of cloud services [29].

Hardware virtualization offers an abstract computing platform to the users instead of the physical characteristics, such as raw computing, storage, network resources [1]. Virtualization also enables encapsulation for the applications, so that they can be installed, configured and maintained [30].

In a multitenant architecture, a single instance of common code and data is shared between multiple tenants [31]. Besides the requirements of shared hardware resources, shared application and shared database instance, Bezemer et al. [32] requires also high degree of configurability in look-and-feel and workflow from multitenant software. Some researchers consider also multi-instancy as a form of multi-tenancy [33], where a vendor hosts separate instances for each customer within shared hardware [33], [34].

Web service represents communication over the HTTP protocol, where the customers use a browser to use the application [1]. SaaS is therefore also a delivery model, software that is available through the network.

Configurable software offers the possibility for users to modify the application's appearance and behavior through metadata services to meet their needs. These configuration changes might refer to user interface and branding (graphics, colors, fonts, logos, etc.), workflow and business processes, extensions to the data model and access control [2].

2.3 Revenue Logic and Software Pricing Models

The revenue logic describes the structure of revenues, how the company makes money by serving its customers [14], [18]. In software industry, the most common revenue streams are: i) monthly or annual subscription fees, ii) advertising based revenue, iii) transaction based revenue (customers are charged based on the number of transactions they perform), iv) premium based revenue (revenue is generated from charging for premium versions besides the free versions), v) revenue from implementation and maintenance services and vi) software licensing [28], [35]–[37].

Software pricing in these above introduced revenue models may base on different aspects. The software pricing model parameters of Lehmann and Buxmann [38] and the SBIFT model of Iveroth et al. [39] are taken into account in the classification of cloud pricing models that describes these models along 7 dimensions [40]:

1. **Scope** represents the granularity of the offer, whether it is priced as a package or different prices are given for different functionalities.
2. **Base** represents the information base the price is set on. The price might be decided based on cost considerations, the competitors' prices, based on performance or customer value.
3. **Influence** represents the ability of buyers and sellers to influence the price, and it contains the options Pricelist, Negotiation, Result-based price, Pay-what-you-want, Auction and Exogenous pricing.
4. **Formula** represents the connection between price and volume, and it contains different variations of fix and variable price components.
5. **Temporal rights** represent the length of service's usage period, and it can be Perpetual, Subscription-based or Pay-per-use.
6. **Degree of discrimination** represents the level of price variety depending on the buyer. The software may be offered to the customers with a different price in different regions or with a price dependent on the time of buying. The price can depend on the acquired volume, software's quality, or it might be even customer-specific.
7. **Dynamic pricing strategy** represents the strategy of dynamic price change over time. Penetration, skimming or hybrid pricing strategies belong to this dimension.

It can be noted, that these 7 dimensions of cloud pricing framework are different by nature: the dimensions Base and Dynamic pricing strategy represents long-term, strategic decisions made usually by the upper management; while the other five dimensions describe the elements of pricing models that can be modified more easily.

We chose to use this framework as a starting point for the present study, since it provides the most state-of-the-art and the most integrative work in the current pricing literature in cloud context. The framework adopts general pricing model elements to software business and cloud context, allowing researchers and practitioners to study different pricing model aspects in a systematic, holistic way.

SaaS business model has an altered licensing scheme compared to the traditional software business, where acquiring a perpetual use license represents the common method of transaction [5]. Instead, in SaaS the customer organization and the software firm agree on a subscription and the software firm develops, deploys and operates the software application in its datacenter of choice. This can been interpreted as separating the ownership of software from its use [41], [42], hence software is provided and consumed as a service rather than as a product. Contemporary SaaS pricing models have been studied notably by Lehmann and Buxmann [38], [43]. However, their studies focus on the current pricing models of SaaS vendors, rather than how pricing models have changed together with changes in technologies and value propositions.

2.4 Research Gap and Hypothesis Development for the Current Study

In our review of the extant literature, we searched for prior work related to cloud technologies, SaaS and pricing models but also the business model concept with a special focus on changes in business models that occurred as a response to technological changes. We found that different aspects of cloud computing have been received moderate attention from the researchers; however, despite of its importance, prior literature lacks empirical studies on how software firms *changed* their pricing models due to adopting cloud computing technologies. In current study therefore we focus on the role of cloud computing technologies in the pricing models of software firms.

In software business, as a result of technological changes and competitive forces, there is a gradual shift in business models towards increasing service revenues [28]. With the emergence of cloud computing, software firms not only implement technological changes by introducing multi-tenancy, hardware virtualization, configurability and internet-based delivery, but these technological characteristics imply also changes to the revenue logic. SaaS software is often offered through the subscription model billed monthly or even in shorter periods [38]. SaaS vendors may often provide their prices through pricelists on their websites [43], indicating more transparent and unified pricing across customers, where the influence of the customers on prices decreases [40]. A cloud solution is a result of co-operation of different value chain partners, where the SaaS provider might pass the usage-based pricing metrics derived from the PaaS provider to the end customers. Both customers and providers might prefer simple pricing models where different functionalities are bundled into one package with one price. [38], [40], [43]

Based on the claimed characteristics of software firms, we assess pricing model changes caused by introducing cloud computing technologies through changes in the pricing model elements and we hypothesize that:

H1. Adopting cloud computing technologies, i.e. introducing hardware virtualization, multi-tenancy, internet-based usage of the software and configuration through internet is associated with change towards 1) simpler pricing 2) less *negotiation 3) usage-based pricing 4) shorter contracts and 5) more unified pricing across customers.*

SaaS software is argued to be more standardized than the traditional software: only a limited set of functionalities is provided to a larger market segment instead of customer-specific solutions [4]. Changes in value proposition imply changes also in other business model elements, such as the pricing model [10], [46]. Therefore, we assess whether pricing model changes are caused by changes in value proposition and we hypothesize that:

H2. Standardizing the value proposition, implementing a limited set of new functionalities is associated with change towards 1) simpler pricing 2) less negotiation 3) usage-based pricing 4) shorter contracts and 5) more unified pricing across customers.

3 Research Method

3.1 Data Collection

The goal of our empirical study was to capture changes in software firms' pricing models due to adoption of cloud technologies. The data used in this study was collected as part of the annual Finnish software industry survey whose primary aim is to gather the information about the current state of software industry. The definition of software firm followed the tradition of the Software Industry Survey[1], focusing on all Finnish companies whose main activity is to provide software as products or services to the customers. The details of the survey can be found online, so in this study we describe the sample and the data collection procedure only shortly.

The survey follows a modified version of the tailored design [44] and collects data using letters and web-based form with email invitations. The mailing list of the survey contained key informants of 4878 software firms. The data collection started in April and ended in June 2013. The respondents were contacted five times and the data gathering resulted in receiving 379 complete and 121 partial responses.

After collecting the data, we used a filter to select the companies appropriate for the goal of this study. As our focus was on firms providing Software-as-a-Service, which originate from either software product firms or software services firms, we excluded producers of embedded software and software resellers from the analysis. Further, since the objective of this study was to examine the factors causing changes in the firms' pricing models, we excluded software firms younger than two years from the analysis. In total, 324 usable responses from software companies matched our inclusion criteria and were used for the analysis.

3.2 Concepts and Their Operationalization

We conceptualized the pricing model of software firms through its dimensions in the cloud pricing framework [40]. The pricing model incorporates the granularity of the offer, the customers' negotiation level, the pricing formula consisting of fix and

[1] See `http://softwareindustrysurvey.org` for details about the survey.

variable price components, the temporal rights and price discrimination [38]–[40]. Cloud technology includes hardware virtualization, multi-tenancy, web-based software and configurability [1], [2]. Value proposition was conceptualized through the firms' product/service portfolio that is offered to the customers [19], [45].

Since the primary goal of the survey was different from the aims of this study, we had to choose between investigating specific changes in the pricing models with single-item measures or studying only one pricing aspect in detail. The aspects of SaaS pricing are diverse, therefore we could not follow the suggestion of the configuration approach [46] to measure one aspect and infer changes to the whole pricing model. Thus, we used single-item measurements for measuring and interpreting various pricing model changes.

The dependent variables of this study measure changes in software firm's pricing model during the last three years. We designed the variables based on the characteristics of assumed SaaS pricing models: capturing change toward having simpler pricing model (labelled "Scope"), toward less negotiation ("Influence"), toward usage-based pricing ("Formula"), toward committing to shorter contracts than before ("Temporal rights") and toward more unified pricing across the customers ("Discrimination"). We excluded the dimensions "Base" and "Dynamic pricing strategy" from our research setting due to their long-term, strategic nature and rather concentrated on different operative aspects on pricing models.

Measuring change in the value proposition was based on the assumption that SaaS firms standardize their products and services and implement fewer new functionalities to their products/services than before. The five dependent variables and the independent variable "Standardization" and "Fewer functionalities" were measured with the question "How well these statements describe the change of your company's business model during the last three years?", where response options were anchored ranging from "1=strongly disagree" to "5=strongly agree".

The independent variables measuring technology adoption are dummy (binary) variables that describe whether or not the companies use hardware virtualization (labelled "Virtualization") multi-tenancy (labelled "Multi-tenancy"), web-based software (labeled "Online delivery") and configurability (labelled "Configurability") in their products and services. These were measured by the question "Which cloud computing features were used in your company's products or services in 2012?", and had the options "Hardware virtualization", "Multi-tenancy", "Internet-based usage of product or service" and "Configuration through internet (Customer self-service)".

The control variables are the size and age of the company ("ln(Size)" and "ln(Age)", respectively). The proxy for the size of the company is the firm's revenue in 2012 and the company's age is determined based on the age of the firm in 2012. Using these control variables is justified. A larger company may have better resources to initiate and execute changes compared to smaller firms with limited resources. On the other hand, the more mature companies are likely to suffer from inertial forces within the organization that obstructs changes [47].

3.3 Data Analysis

In this study we used non-parametric correlations and multivariate ordinal regression analyses to investigate the hypotheses. In particular, non-parametric correlations are used to reveal associations between cloud technologies, changes in value proposition and elements of pricing models. The ordinal regression analyses were employed to assess the pricing model changes attributable to adoption of cloud technologies and changes in value proposition. Ordinal regressions treat each ordinal value as an independent variable; thus it is possible to examine parameter estimates for a certain range of values within an independent variable [48].

Before running the data analyses, exploratory tests were carried out to choose the most appropriate statistical methods. Specifically, after realizing that the dependent variables were negatively skewed, we run the Shapiro-Wilk's test of normality and the test was significant. Thus, the sample did not come from normally distributed population; therefore we chose to use non-parametric statistics. We also investigated the potential presence of outliers. After exploring the data, we detected four influential responses visually using box plots and removed them from the analysis. Next, we applied Harman's single-factor test to check the common method variance problem, that is typical in case of survey research [49]. The unrotated factor solution did not reveal a single factor, which would account for the majority of the variance in the model, suggesting that the method variance would not be a problem in the data. Different concerns are related to the ordinal regression analyses, such as the multicollinearity of the independent variables, the choice of link function, and the proportional odds assumption. From the correlation statistics presented in the Table 1, we did not detect high correlations between the independent variables; thus, multicollinearity would not impede the results. Our choice of link function was driven by the distribution of the ordinal outcome as suggested by the literature [50], and we employed Cauchit for the

Table 1. Non-parametric correlations between the variables

	Spearman rho		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Scope	Coefficient	1.000												
		Significance													
2	Influence	Coefficient	.222	1.000											
		Significance	.001	.											
3	Formula	Coefficient	.218	.106	1.000										
		Significance	.001	.104	.										
4	Temporal rights	Coefficient	.044	.045	.140	1.000									
		Significance	.501	.488	.032	.									
5	Discrimination	Coefficient	.489	.256	.185	.030	1.000								
		Significance	.000	.000	.005	.644	.								
6	Virtualization	Coefficient	.089	.042	.174	-.007	.141	1.000							
		Significance	.170	.519	.007	.911	.029	.							
7	Multi-tenancy	Coefficient	.171	.197	.230	-.093	.159		1.000						
		Significance	.008	.002	.000	.150	.014		.						
8	Online delivery	Coefficient	.131	.040	.182	-.025	.130			1.000					
		Significance	.043	.534	.005	.697	.045			.					
9	Configurability	Coefficient	.234	.146	.180	.020	.125				1.000				
		Significance	.000	.024	.005	.762	.053				.				
10	Standardization	Coefficient	.189	.144	.276	-.020	.261	.230	.200	.106	.070	1.000			
		Significance	.003	.026	.000	.764	.000	.000	.002	.100	.278	.			
11	Fewer functionalities	Coefficient	.080	.165	.135	.186	.141	-.060	-.008	-.068	.031	.143	1.000		
		Significance	.222	.012	.040	.004	.032	.354	.901	.297	.634	.028	.		
12	ln(Age)	Coefficient	-.056	-.076	.047	.063	.025	-.064	-.045	-.059	-.107	.010	.050	1.000	
		Significance	.387	.242	.475	.334	.697	.309	.469	.343	.085	.876	.444	.	
13	ln(Size)	Coefficient	-.127	-.033	.005	.043	.017	.154	.169	.040	.049	.114	-.102	.159	1.000
		Significance	.056	.621	.941	.519	.802	.016	.008	.539	.443	.086	.124	.009	.

model “DV=Scope” (outcome with many extreme values), Probit for the model “DV=Influence” (the underlying latent trait of the ordinal outcome is normally distributed) and Logit for the models “DV=Formula” and “DV=Discrimination” (evenly distributed categories). Finally, to test the proportional odds assumption the authors ran tests of parallel lines in SPSS. With all the models, the Chi-Square statistics were insignificant, indicating that the assumption was not violated.

4 Results

The variables and their non-parametric correlations are visible in Table 1. The results show that some variables capturing the changes in software firms’ pricing models are positively correlated with the adoption of cloud technologies. Specifically, the change towards having simpler pricing model (Scope) is associated with multi-tenancy, online delivery, configurability; change towards less negotiation (Influence) is positively correlated with multi-tenancy and configurability; change towards usage-based pricing (Formula) is associated with virtualization, multi-tenancy, online delivery and configurability; and change towards more unified pricing across the customers (Discrimination) is associated with virtualization, multi-tenancy and online delivery. However, change towards shorter subscription periods (Temporal rights) is not correlated with the use of the technologies; thus, we exclude the ordinal regression model explaining this change by introducing cloud technologies from this study.

Change in value proposition toward more standardized product/service or towards fewer functionalities is associated with change in different pricing model elements. Table 1 also shows correlations between dependent variables.

Table 2. Ordinal regression models with parameter estimates

	DV=Scope			DV=Influence			DV=Formula			DV=Discrimination		
	Estimate	StdErr	Sig.	Estimate	StdErr	Sig.	Estimate	StdErr	Sig.	Estimate	StdErr	Sig.
DV ordinal level =1	-40.651	31.242	.193	-1.477	.527	.005	-.339	.919	.712	-.958	.990	.333
DV ordinal level =2	-.996	.945	.292	.073	.510	.887	.924	.895	.302	1.154	.913	.206
DV ordinal level =3	.749	.947	.429	1.060	.513	.039	2.684	.910	.003	2.760	.926	.003
DV ordinal level =4	4.911	1.306	.000	2.580	.544	.000	5.419	.965	.000	6.186	1.015	.000
virtualization	-.132	.285	.644	-.029	.164	.861	.218	.293	.456	.133	.294	.650
multi-tenancy	.943	.318	.003	.368	.171	.031	.557	.308	.071	.294	.309	.342
online delivery	.069	.304	.821	-.034	.182	.850	.425	.320	.184	.196	.323	.544
configurability	1.043	.311	.001	.155	.166	.351	.351	.297	.236	.226	.301	.453
standardization	.329	.140	.019	.101	.079	.199	.518	.140	.000	.394	.141	.005
fewer functionalities	.041	.143	.776	.252	.083	.002	.214	.145	.139	.264	.151	.080
ln(Age)	-.065	.186	.725	-.199	.104	.056	.180	.183	.325	.118	.187	.527
ln(Size)	-.081	.057	.153	-.009	.028	.753	-.037	.050	.457	.027	.051	.588
Pseudo R^2 (Nagelkerke)	.160			.115			.172			.098		
Pseudo R^2 (controls only)	.003			.016			.004			.004		
Model fitting information	536.509	35.630	.000	548.369	24.924	.002	543.388	38.424	.000	509.455	20.534	.008

Results from the ordinal regressions of the four models are shown in Table 2, which reports the regression parameter estimates for the levels of dependent variables (“DV”), for the independent variables and controls. The table also reports two pseudo r-squares of Nagelkerke – for the full model and for controls only – which assess the overall goodness of fit of the ordinal regression models. While the values give some indication of the strength of the associations between the dependent and the predictor variables, the authors note that these r-squares should not be interpreted similarly to the OLS regressions. However, comparing the r-squares between a model including only controls and the full model, the higher r-square on each full model indicates better prediction on the outcome. Lastly, the tables include model fitting information for the final models; −2 log-likelihood, Chi-square and significance. The values are statistically acceptable for all models. This means that the models yield predictions more fitting than the marginal probabilities for the dependent variable categories.

Focusing on the ordinal regression parameter estimates for this study, the adoption of multi-tenancy is significant in predicting the change towards having simpler pricing model (in model "DV=Scope", Est.=943, Sig.=.003), towards less negotiation ("DV=Influence", Est. =.368, Sig. =.031) and to some extent notable in predicting the change towards usage-based pricing ("DV=Formula, Est. =.557, Sig. =.071). Besides, software firms with highly configurable applications are more likely to change their pricing model towards having simpler pricing model ("DV=Scope, Est. =1.043, Sig. =.001). The change towards simpler pricing model is also predicted by the standardization of the products and services ("DV=Scope", Est. =.329 Sig. =.019). Besides, change in value proposition towards more standardized product/service is a better predictor of changes towards usage-based pricing ("DV=Formula", Est. = .518, Sig.=.000) and toward more unified pricing across the customers (DV="Discrimination", Est.= .394, Sig.= .005) than the cloud technologies. Furthermore, change towards fewer new functionalities is the best predictor for change towards less negotiation (DV="Influence", Est.=.252, Sig.=.002).

5 Discussion

The current study supports most of our hypotheses deriving from the literature regarding the pricing model changes due to adoption of cloud computing technologies. The use of virtualization, multi-tenancy, online delivery and configurability are associated with the increased use of usage-based pricing. Besides, the use of multi-tenancy and configurability is associated with less negotiation with the customers. This can be explained by the fact that multi-tenancy constraints the customers' options for customization [51] that results in the customers' lower influence on both the product/service and its pricing. In addition to the above mentioned associations, the use of multi-tenancy, online delivery and configurability is significantly correlated with change towards simpler pricing with less pricing components. Also, the use of hardware virtualization, multi-tenancy and online delivery correlates with change towards more unified pricing across customers.

Based on the results, multi-tenancy is the most influential factor among cloud computing technologies that affects 4 out of 5 pricing model dimensions. Since multi-tenancy is the indicator of a cloud-mature, standardized application, it is not surprising that the use of it implies fundamental changes in the pricing as well. Prior research accentuates the role of multi-tenancy in the success of SaaS vendors [33].

However, based on this finding we claim that besides implementing multi-tenancy, changes most likely occur also in business model elements, such as the revenue logic, and these changes contribute *together* to the success. On the other hand, keeping our research method in mind, we cannot rule out the possibility that online delivery, configurability and virtualization might be introduced earlier than 3 years, leaving some dimensions of pricing models untouched during these last years.

It has to be noted that based on the empirical findings, the use of cloud computing technologies does not imply change towards shorter subscription contracts. Even though the use of these technologies enables shorter subscription contracts with the customers, the results show that the aim of software companies is to develop longer customer relationships. A possible explanation for this could be the possibly heavy competition in the market and the firms' high initial investments whose return need to be secured.

In the current study, besides technological characteristics and changes in pricing model elements, our model incorporated also changes towards more standardized products/services and fewer functionalities. The results show that change in value proposition explains most of the changes in different pricing model elements. This underscores the interrelation of different business model elements suggested by the literature (e.g. [10], [47]); namely, decisions to individual business model elements may affect several aspects of the firm.

Firms that standardize their products and services change also their pricing model; thus, revenue logic is highly important in a firm's strategy that needs attention from the managers. Besides standardizing the software, unifying the pricing across customers and using more volume dependent pricing components is justified. Standardized, less customer-specific software can be sold for the same price for different customers since the minimal customization work offsets the differences in the development costs. Standard software may generate more revenues with employing usage-based pricing in case there are big differences in the users' demand. With incorporating usage-dependent pricing components into the revenue logic, the infrastructure costs are passed directly from the provider to the customers. This way the company is able to catch also the long-tail of the market.

The analysis shows also that companies that implement fewer new functionalities give less negotiation power to their customers. Concentrating on the core functionalities leaves no or minimal room for user-specific customization work, thus, it makes negotiation unnecessary. Hence, SaaS firms offering standard software with a limited set of core functionalities usually employ pricelists in their pricing to attract customers.

The strength of associations between variables in this study indicates that implementing technological and business models changes is complex. The software firm's managers' cognitive processes may play an important role in adjusting different business model elements, in some cases even greater than the technological opportunities. We consider also the possibility that the software firm had already executed the changes before, thus, there had not been changes in the last three-year period.

During the study, we paid special attention to the common possible bias in survey research, such as measurement errors, problems related to sampling, coverage, and non-response [44]. To reduce the risk of measurement error we attained guidance on the survey questions from both researchers and practitioners in the field. Whenever available, we applied scales that have been tested in previous studies. One of the concerns with the measurements is the use of single-item measures, which are argued to insufficiently capture the conceptual domain. However, this claim has been challenged by DeVellis [52] by arguing that each item of a scale is precisely as good measure as any other of the scale items and that the items' relationship and errors to the variable are presumed identical. Understanding of this perplexity guided the authors not to make claims about the changes in pricing model dimensions (e.g. scope of the pricing model), but rather about the parameters (e.g. the number of pricing model components).

The software industry survey practically covers and contacts all the Finnish software companies; therefore we consider coverage and sampling errors irrelevant. The overall sampling rate for the software industry survey nonetheless is roughly 10 percent, which suggests a potential risk of non-response bias. However, the effective sample contained software firms of all types, ages and sizes, and the concern is principally if there are theoretically relevant differences between respondents and non-respondents. In this case, the effective sample contained sufficient variety in dependent variables to support the analysis of the hypotheses.

6 Conclusions

Using cloud computing technologies in software applications implies changes also to the business aspects of software firms; among which pricing is extremely important in achieving success in the competitive SaaS market. The current study fills a research gap in the current literature by focusing on the impact of deploying cloud computing technologies on different pricing model elements. In this paper the results of the research are presented related to the impact of hardware virtualization, multi-tenancy, online delivery and configurability on different dimensions of pricing models, such as the scope of it, the influence of the customers on pricing, the use of usage-based pricing, the temporal rights and price discrimination across customers.

After analyzing an effective sample of 324 software firms, we conclude that the use of cloud computing technologies implies changes in different dimensions of the pricing models. The results show that multi-tenancy is the most influential factor, affecting 4 out of 5 dimensions, while hardware virtualization, online delivery and configurability are associated with changes in some of the aspects of the pricing model. Software firms that use cloud computing technologies in their products and services seem to make their pricing model simpler, use usage-based pricing, reduce the customers' influence and unify their pricing across customers. They do not, however, shorten the length of the contracts with their customers. The current study also revealed that changes in pricing models happens together with changes in the value proposition; this underlines the interrelation of different business model elements suggested also by the literature (e.g. [10], [47]).

This study is the first to examine the changes in pricing models of SaaS firms empirically and therefore the authors suggest these findings to serve as a starting point for future studies. The practical implication of this study is an increased understanding about how the SaaS vendors are changing their business models and consequently how the market of software products and services is evolving as a result of recent technological advances. As the market is transforming to embrace the promises of cloud computing technologies, studies on business models offer predictions about what are the viable configurations of business models and how deployment of technologies changes the configurations. Since the survey is limited to Finland, the study does not necessarily provide a representative illustration on SaaS firms in a global context; therefore similar studies in other countries are welcome to complement the results.

References

1. Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J., Ghalsasi, A.: Cloud computing—The business perspective. Decision Support Systems 51(1), 176–189 (2011)
2. Chong, F., Carraro, G.: Architecture strategies for catching the long tail. MSDN Library, Microsoft Corporation, pp. 9–10 (2006)
3. Weinhardt, C., Anandasivam, D.-I.-W.A., Blau, B., Borissov, D.-I.N., Meinl, D.-M.T., Michalk, D.-I.-W.W., Stößer, J.: Cloud computing–a classification, business models, and research directions. Business & Information Systems Engineering 1(5), 391–399 (2009)
4. Benlian, A., Hess, T.: Opportunities and risks of software-as-a-service: Findings from a survey of IT executives. Decision Support Systems 52(1), 232–246 (2011)
5. Choudhary, V.: Comparison of software quality under perpetual licensing and software as a service. Journal of Management Information Systems 24(2), 141–165 (2007)
6. Stuckenberg, S., Fielt, E., Loser, T.: The impact of software-as-a-service on business models of leading software vendors: experiences from three exploratory case studies. In: Proceedings of the 15th Pacific Asia Conference on Information Systems, PACIS 2011 (2011)
7. Tyrväinen, P., Selin, J.: How to sell saaS: A model for main factors of marketing and selling software-as-a-service. In: Regnell, B., van de Weerd, I., De Troyer, O. (eds.) ICSOB 2011. LNBIP, vol. 80, pp. 2–16. Springer, Heidelberg (2011)
8. Gourville, J., Soman, D.: Pricing and the Psychology of Consumption. Harvard Business Review 80(9), 90–96 (2002)
9. Piercy, N.F., Cravens, D.W., Lane, N.: Thinking strategically about pricing decisions. Journal of Business Strategy 31(5), 38–48 (2010)
10. Teece, D.J.: Business models, business strategy and innovation. Long Range Planning 43(2), 172–194 (2010)
11. Anandasivam, A., Premm, M.: Bid price control and dynamic pricing in clouds. In: ECIS 2009 Proceedings (2009)
12. Schramm, T., Wright, J., Seng, D., Jones, D.: Six questions every supply chain executive should ask about cloud computing. Accenture Institute for High Performance (2010)
13. Cusumano, M.A.: The changing labyrinth of software pricing. Communications of the ACM 50(7), 19–22 (2007)
14. Magretta, J.: Why business models matter. Harvard Business Review 80(5), 86–92 (2002)

15. Osterwalder, A., Pigneur, Y., Tucci, C.L.: Clarifying business models: Origins, present, and future of the concept. Communications of the Association for Information Systems 16(1), 1–25 (2005)
16. Baden-Fuller, C., Morgan, M.S.: Business models as models. Long Range Planning 43(2), 156–171 (2010)
17. Casadesus-Masanell, R., Ricart, J.E.: From strategy to business models and onto tactics. Long Range Planning 43(2), 195–215 (2010)
18. Demil, B., Lecocq, X.: Business model evolution: in search of dynamic consistency. Long Range Planning 43(2), 227–246 (2010)
19. Chesbrough, H., Rosenbloom, R.S.: The role of the business model in capturing value from innovation: evidence from Xerox Corporation's technology spin-off companies. Industrial and Corporate Change 11(3), 529–555 (2002)
20. Cavalcante, S., Kesting, P., Ulhøi, J.: Business model dynamics and innovation (Re) establishing the missing linkages. Management Decision 49(8), 1327–1342 (2011)
21. Bharadwaj, A., El Sawy, O.A., Pavlou, P.A., Venkatraman, N.: Digital Business Strategy: Toward a Next Generation of Insights. MIS Quarterly 37(2), 471–482 (2013)
22. Kamoun, F.: Rethinking the business model with RFID. Communications of the Association for Information Systems 22(1), 35 (2008)
23. Timmers, P.: Business models for electronic markets. Electronic Markets 8(2), 3–8 (1998)
24. Wirtz, B.W., Schilke, O., Ullrich, S.: Strategic development of business models: implications of the Web 2.0 for creating value on the internet. Long Range Planning 43(2), 272–290 (2010)
25. Ojala, A., Tyrväinen, P.: Developing Cloud Business Models: A Case Study on Cloud Gaming. IEEE Software 28(4), 42–47 (2011)
26. Novelli, F.: A mixed-methods research approach to investigate the transition from on-premise to on-demand software delivery. In: Vanmechelen, K., Altmann, J., Rana, O.F. (eds.) GECON 2012. LNCS, vol. 7714, pp. 212–222. Springer, Heidelberg (2012)
27. Campbell-Kelly, M.: Historical reflections: The rise, fall, and resurrection of software as a service. Communications of the ACM 52(5), 28–30 (2009)
28. Cusumano, M.A.: The changing software business: Moving from products to services. Computer 41(1), 20–27 (2008)
29. Mell, P., Grance, T.: The NIST Definition of Cloud Computing. Gaithersburg, MD: National Institute of Standards and Technology (2011)
30. Foster, I., Zhao, Y., Raicu, I., Lu, S.: Cloud computing and grid computing 360-degree compared. In: Grid Computing Environments Workshop, GCE 2008, pp. 1–10 (2008)
31. Bezemer, C.-P., Zaidman, A.: Multi-tenant SaaS applications: maintenance dream or nightmare? In: Proceedings of the Joint ERCIM Workshop on Software Evolution (EVOL) and International Workshop on Principles of Software Evolution (IWPSE), pp. 88–92 (2010)
32. Bezemer, C.-P., Zaidman, A., Platzbeecker, B., Hurkmans, T., Hart, A.: Enabling multi-tenancy: An industrial experience report. In: 2010 IEEE International Conference on Software Maintenance (ICSM), pp. 1–8 (2010)
33. Guo, C.J., Sun, W., Huang, Y., Wang, Z.H., Gao, B.: A framework for native multi-tenancy application development and management. In: Proceedings of CEC/EEE 2007, pp. 551–558 (2007)
34. Ju, J., Wang, Y., Fu, J., Wu, J., Lin, Z.: Research on key technology in SaaS. In: International Conference on Intelligent Computing and Cognitive Informatics (ICICCI), pp. 384–387 (2010)

35. D'souza, A., Kabbedijk, J., Seo, D., Jansen, S., Brinkkemper, S.: Software-As-A-Service: Implications For Business And Technology in Product Software Companies. In: PACIS 2012 Proceedings (2012)
36. Ojala, A.: Software renting in the era of cloud computing. In: IEEE 5th International Conference on Cloud Computing, pp. 662–669 (2012)
37. Ojala, A.: Revenue models in SaaS. IT Professional 15(3), 54–59 (2012)
38. Lehmann, S., Buxmann, P.: Pricing Strategies of Software Vendors. Business & Information Systems Engineering 1(6), 452–462 (2009)
39. Iveroth, E., Westelius, A., Petri, C.-J., Olve, N.-G., Cöster, M., Nilsson, F.: How to differentiate by price: Proposal for a five-dimensional model. European Management Journal 31(2), 109–123 (2013)
40. Laatikainen, G., Ojala, A., Mazhelis, O.: Cloud Services Pricing Models. In: Herzwurm, G., Margaria, T. (eds.) ICSOB 2013. LNBIP, vol. 150, pp. 117–129. Springer, Heidelberg (2013)
41. Turner, M., Budgen, D., Brereton, P.: Turning software into a service. Computer 36(10), 38–44 (2003)
42. Laplante, P.A., Zhang, J., Voas, J.: What's in a name? Distinguishing between SaaS and SOA. IT Professional 10(3), 46–50 (2008)
43. Lehmann, S., Draisbach, T., Buxmann, P., Dörsam, P.: Pricing of Software as a Service – An Empirical Study in View of the Economics of Information Theory. In: Cusumano, M.A., Iyer, B., Venkatraman, N. (eds.) ICSOB 2012. LNBIP, vol. 114, pp. 1–14. Springer, Heidelberg (2012)
44. Dillman, D.A.: Mail and internet surveys: The tailored design method. Wiley, New York (2000)
45. Zott, C., Amit, R., Massa, L.: The Business Model: Recent Developments and Future Research. Journal of Management 38(1), 375–414 (2011)
46. Miller, D.: Configurations of strategy and structure: Towards a synthesis. Strategic Management Journal 7(3), 233–249 (1986)
47. Hacklin, F., Wallnöfer, M.: The business model in the practice of strategic decision making: insights from a case study. Management Decision 50(2), 166–188 (2012)
48. McCullagh, P.: Regression models for ordinal data. Journal of the royal statistical society. Series B (Methodological), 109–142 (1980)
49. Podsakoff, P.M., MacKenzie, S.B., Lee, J.-Y., Podsakoff, N.P.: Common method biases in behavioral research: a critical review of the literature and recommended remedies. Journal of Applied Psychology 88(5), 879 (2003)
50. Norusis, M.: SPSS 16.0 guide to data analysis. Prentice Hall Press (2008)
51. Xin, M., Levina, N.: Software-as-a-service model: Elaborating client-side adoption factors. In: Proceedings of the 29th International Conference on Information Systems (2008)
52. DeVellis, R.F.: Scale development: Theory and applications. Sage (2011)

IV

ROLE OF ACQUISITION INTERVALS IN PRIVATE AND PUBLIC CLOUD STORAGE COSTS

by

Gabriella Laatikainen, Oleksiy Mazhelis & Pasi Tyrväinen, 2014

Decision Support System, vol. 57, pp. 320-330

Decision Support Systems 57 (2014) 320–330

Contents lists available at ScienceDirect

Decision Support Systems

journal homepage: www.elsevier.com/locate/dss

Role of acquisition intervals in private and public cloud storage costs

Gabriella Laatikainen *, Oleksiy Mazhelis, Pasi Tyrväinen

Department of Computer Science and Information Systems University of Jyväskylä, Jyväskylä, Finland

ARTICLE INFO

Article history:
Received 26 November 2012
Received in revised form 17 September 2013
Accepted 22 September 2013
Available online 9 November 2013

Keywords:
Storage services
Cloud storage
Cost model
Acquisition interval

ABSTRACT

The volume of worldwide digital content has increased nine-fold within the last five years, and this immense growth is predicted to continue in the foreseeable future to reach 8 ZB by 2015. Traditionally, organizations proactively have built and managed their private storage facilities to cope with the growing demand for storage capacity. Recently, many organizations have instead welcomed the alternative of outsourcing their storage needs to the providers of public cloud storage services due to the proliferation of public cloud infrastructure offerings. The comparative cost-efficiency of these two alternatives depends on a number of factors, such as the prices of the public and private storage, the charging and the storage acquisition intervals, and the predictability of the demand for storage. In this paper, we study the relationship between the cost-efficiency of the private vs. public storage and the acquisition interval at which the organization re-assesses its storage needs and acquires additional private storage. The analysis in the paper suggests that for commonly encountered exponential growth of storage demand, shorter acquisition intervals increase the likelihood of less expensive private storage solutions compared with public cloud infrastructure. This phenomenon is also numerically illustrated in the paper using the storage needs encountered by a university back-up and archiving service as an example. Because the acquisition interval is determined by the organization's ability to foresee the growth of storage demand, via provisioning schedules of storage equipment providers, and internal practices of the organization, among other factors, organizations that own a private storage solution may want to control some of these factors to attain a shorter acquisition interval and thus make the private storage (more) cost-efficient.

1. Introduction

According to the IDC, the global volume of digital content has exhibited exponential growth and will grow from 1.8 ZB in 2011 to 2.7 ZB in 2012 and ultimately reach 35 ZB by 2020 [5,6]. As the volume of digital content grows, the global need for storage capacity rapidly increases, too.

To cope with the growing demand for storage, organizations may proactively build their private storage capacity or may alternatively opt for outsourcing their storage to the providers of public cloud infrastructure services, such as Amazon Simple Storage Service (S3), Box.com, and Apple iCloud. Decision makers consider several factors when they decide on possible adoption, such as cost, elasticity, data availability, security, data confidentiality and privacy, regulatory requirements, reliability, performance, integration with other services, personal preference, and added values [10]. However, cost considerations are perceived both as a risk and an opportunity, and the expected cost advantage is the strongest decisional factor that affects the perceived opportunities of IT executives [2].

If the organization decides to store its data in-house, it periodically estimates its future demand for storage and then proactively acquires and manages the storage infrastructure internally. Conversely, the use of cloud-based storage services gives the organization the flexibility to rapidly increase its storage capacity as the demand for storage grows, as well as the possibility to pay only for the volume of storage the organization actually uses within each charging period.

Because the cloud infrastructure capacity is usually paid for only when used, the cloud infrastructure providers include a so-called utility (pay-per-use) premium into their pricing [29]. As a result, the unit price per unit of time of a public cloud infrastructure capacity is usually more expensive compared with the unit cost of private capacity [29,9]. Still, if the demand for infrastructure services exhibits periodical or random peaks, the adoption of public cloud infrastructure is likely to offer cost advantages to organizations over the private infrastructure: this advantage is because the high premium charged by the public cloud provider is compensated by avoiding extensive periods of time when the private infrastructure would remain idle [29,12].

However, as opposed to the fluctuating demand for computing resources, the demand for storage often accumulates over time because newly created digital content only partially supersedes the already stored files. As a result, the use of public storage services may prove more expensive compared with the private solutions in the long term [27].

The cost-efficiency of public vs. private storage depends on a number of factors, such as the premium charged by the provider of public cloud infrastructure, the charging period (for the public storage) and

* Corresponding author. Tel.: +358 451444700.
E-mail addresses: gabriella.g.laatikainen@jyu.fi (G. Laatikainen), mazhelis@jyu.fi (O. Mazhelis), pasi.tyrvainen@jyu.fi (P. Tyrväinen).

0167-9236/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.dss.2013.09.020

the storage acquisition interval (for the private storage), the intensity of incurred data communications, the predictability of the growth of storage needs and the storage growth profile [27,30]. Due to the continuously increasing storage demand, the length of the acquisition intervals and growth predictability are among the most critical factors in storage cost analysis; however, they have to date not been studied in detail. Therefore, we study the effect of the private storage acquisition interval on the cost-efficiency of private vs. public storage in this paper. This interval can be determined by the organization's ability to foresee the growth in storage demand, via the provisioning schedule of the storage equipment provider, the internal practices of the organization, etc. The paper analytically shows that for commonly encountered exponential growth of storage demand, shorter intervals for which the organization re-assesses its storage needs and acquires additional storage increase the likelihood that a private storage solution is less expensive compared with the public cloud infrastructure. Numerical experiments are employed to illustrate this dependency using the storage needs encountered by a university back-up and archiving service as an example.

The analysis of storage costs in the paper focuses on the storage needs and their growth and predictability, storage acquisition interval, as well as the costs incurred due to the transfer of data to and from the storage location. The storage costs may also be affected by additional factors, such as the economies and diseconomies of scale, the cost of capital, the required level of availability and durability and the possibility to use provenance data. Combined, these and other factors are likely to have a complex, non-linear effect on the overall costs, which makes them difficult to analyze [12]. To simplify the analysis, these additional factors were assumed to either have a minor effect or similar effect on the costs of both the private and public storage solutions. Hence, these factors are outside of the scope of the paper.

The remainder of the paper is organized as follows. In the next section, the related works on the cost-efficient use of cloud infrastructure are reviewed. In Section 3, an analytical model for comparing the cost efficiency of private vs. public storage is introduced, in which the effect of the acquisition interval is taken into account. Numerical experiments that illustrate the effect of the acquisition interval and its interplay with various other factors are provided in Section 4. In Section 5, the practical implications and limitations of the obtained results are discussed. Finally, Section 6 summarizes the obtained results and outlines the directions for further work.

2. Related works

In recent years, extensive research efforts have been devoted to the cost-efficient use of cloud infrastructure services in general, and cloud storage services in particular. A short overview of the recent research in this domain is provided below.

A number of works have focused on the cost-efficient use of cloud infrastructure and the factors that affect it. In particular, the cost benefit of using cloud bursting, i.e., offloading the computing load during peak times to a public cloud infrastructure, has been analytically investigated in [29,28]. The cost efficient allocation of computing load to the private and the public portions of a hybrid cloud infrastructure was also studied in [8,3] and in [13,12], where the communication overheads were also considered. The cost-optimal time of using the public cloud has been shown to be the inverse of the premium charged by the public cloud provider assuming negligible data communication overheads.

The economies of scale, i.e., the decline in the cost per unit of a service with the number of units produced [22], may affect the cost-efficiency of private vs. public cloud infrastructure as well. These economies of scale are manifested e.g., in the volume discount offered for the cloud infrastructure capacity, and the cost of a hybrid cloud may exceed the cost of a private or a public cloud infrastructure in the presence of such discounts [12].

The cost-optimal allocation of individual computing tasks to private and public cloud resources was also approached as a multi-integer linear programming problem in [24]. Based on the results of a simulation study, the authors found little or no cost benefits in offloading the peaks of the workload, although the preliminary character of the study and the complex nature of the optimization model make it difficult to interpret the results. Walker [27] compared the acquisition and leasing of storage as alternative investment decisions based on their Net Present Value (NPV). The estimation of the NPV considers the dynamics of the demand for storage, the gradual decline of acquired and leased storage prices, the disk replacements due to possible disc failures, and the salvage value of the acquired discs at the end of their use time. Using numerical examples, the authors illustrated that leasing represents a cost-optimal alternative for small- and medium-sized enterprises, whereas acquiring storage is likely to be less expensive in the long term for large enterprises.

Mastroeni and Naldi [11] further revised Walker's model by replacing the deterministic estimation of the pricing dynamics and disc failure dynamics in [27] with probabilistic models. Based on these models, the authors arrive at a probabilistic distribution of differential NPV values and use its median to determine the economically justifiable alternative. Note that in both [27] and [11], the costs are accounted on a yearly basis; thus, the role of acquisition intervals shorter than a year is not visible in these models.

Uttamchandani et al. [26] introduced BRAHMA, a tool that applies constraint-based optimization to cost-optimally supply the storage demand with a mixture of in-house and public cloud storage resources. The tool suggests an optimal placement both for the storage and for the system administrators based on customer storage needs and the projected growth thereof over a look-ahead period, as well as associated service level objectives. The tool helps to identify the optimal sourcing if the customer and the storage service provider have a heterogeneous set of devices and human resources that have different costs. However, to the best of our knowledge, the tool assumes a perfect knowledge of the customer demand growth and fails to consider the storage acquisition intervals; as a result, the cost of the over-provisioned storage is not visible when using the tool.

Constraint-based optimization has also been employed by Trummer et al. [25] to optimally allocate applications to the cloud along with their storage resources. The authors' approach assumes that the resource requirements are known in advance, which is similar to the BRAHMA tool. The effects of imperfect knowledge and resulting storage over-provisioning are not considered.

In addition to acquiring storage capacities, organizations may maximize the cost-efficiency of cloud solutions by storing only the provenance for data and regenerating the rest when needed [1]. Yuan et al. proposed different strategies to find the best trade-off of storage and computational costs by storing the appropriate intermediate data in cloud storage [31,33,32]. Muniswamy-Reddy et al. emphasized the need for incorporating provenance services in cloud storage providers, analyzed several alternative implementations to collect provenance data, and use the cloud as a backend [17,16,15].

Finally, Weinman [30] considered the delay with which the required resource is provisioned and analyzed both the cost of over-provisioning (i.e., unused resources) and under-provisioning (i.e., the opportunity cost of unserved demand). The author discussed the role of provisioning time given a possibility to predict the future demand over a specific forecast visibility; however, the paper only considered cases with a zero forecasting visibility.

In summary, while a number of works have focused on the cost-efficient use of private and public infrastructure resources, relatively little attention has been devoted to the role of the acquisition intervals in the cost-efficient use of private vs. public storage capacity. Therefore, a storage cost model is introduced below in which the effect of the acquisition interval is taken into account.

3. Storage cost model

In this section, the cost constituents of alternative storage approaches are considered, and their total costs are compared. Different cost constituents need to be taken into account depending on whether the storage solution is owned and managed privately by the organization or offered by a public cloud infrastructure provider.

For private storage, the relevant cost constituents include the cost of hardware and software acquisition, integration, configuration, upgrade costs, as well as the recurring costs of renting floor space, power, bandwidth, and the cost of administration and maintenance. The cost of private storage is a function of the demand, its growth pattern and predictability, the time interval between storage acquisitions, and the pricing of the necessary equipment, software, and personnel, as well as various other expenses.

Conversely, the cost of public cloud storage consists of the usage-dependent costs of storage capacity, data transfer, and input/output requests (based on the pricing set by Amazon S3). Depending on the charging policy of the provider, the cost of the storage may be determined by the maximum volume of storage occupied during the charging period: for instance, Amazon Web Services (AWS) offerings apply charges based on the maximum storage capacity used in 12 h.[1]

In addition to the difference in cost constituents, storage is differentially acquired, provisioned, and charged for. Namely, private storage needs to be acquired in advance to meet the expected demand growth until the next acquisition time, and it incurs volume-dependent costs irrespective of storage use. However, public storage can be deployed virtually instantly as the demand grows, and it is charged based on the volume of the storage actually used within the charging period. Furthermore, in-house storage needs to be acquired in excess depending on the accuracy of storage prediction (which is not necessary in public cloud storage). Nevertheless, the price of a unit of in-house storage can be significantly lower than the price of the public cloud. Therefore, we suggest that the cost efficiency of private vs. public storage depends on the price difference of the private and public storage, the interval at which the storage can be acquired, and the accuracy with which the future needs for the storage can be predicted.

Organizations may apply different data storage strategies to trade some of the storage costs to computational costs. In some applications, they may only store the provenance data and regenerate the data when needed, or they may compress data to minimize the overall storage-related expenses. However, incorporating these factors in the analytical model results in a complex analysis task due to the great number of alternative solutions that can be envisioned. Furthermore, based on our knowledge, public cloud providers do not yet offer provenance or compression services to the public [17,16]. Consequently, we assumed that provenance data or compression are not used to reduce storage costs because of space limitations.

The remainder of the section is organized as follows. In the next subsection, we introduce a storage cost model to compare the costs of private and public solutions. We then study the effect of the length of the acquisition period on the cost-efficiency of private vs. public storage for exponential (Section 3.2), linear (Section 3.3), and logarithmic growth (Section 3.4). The role of data transfer costs in the storage costs is then analyzed in Section 3.5. Finally, the sensitivity of the cost difference function to the acquisition interval and utility premium are introduced in Section 3.6.

3.1. General storage cost model

Let us define the demand function $s(t) \mapsto \mathbb{R}$ that maps from time to the quantity of needed resources. Due to the increasing growth of storage needs, we can assume that the function is positive and increasing. Let $P_p(s(t))$ denote the price of a unit of storage set by the public storage provider, and let $P_o(s(t))$ denote the total cost of owning a unit of private storage capacity over time t. Both prices are shown as functions of the volume of used or acquired storage capacity $s(t)$, to indicate that the prices can be a subject to volume discounts, as is in the case of AWS storage, for example. Note that $P_p(s(t))$ can be found by consulting price lists of public IaaS vendors, whereas $P_o(s(t))$ needs to be estimated by summing the total costs of acquisition and using the storage over the total period of planned use, T (e.g., the depreciation period) to ultimately derive the share of the total costs during the time, t.

Let us first consider the case of using private storage capacity. Let us assume that the organization is acquiring private storage capacity with an acquisition interval, τ. The organization then needs to predict how much storage it would require within time, τ, i.e., until the next acquisition time. For instance, if $\tau = 12$ month, the firm needs to predict the increase of its storage needs over the next year and acquire the storage accordingly. The cost of acquiring in-house storage capacity, c_o, can then be estimated as follows:

$$c_o = \hat{s}(\tau)p_o(\hat{s}(\tau))\tau, \tag{3.1}$$

where $\hat{s}(\tau)$ is the organization's estimate of the maximum storage needed within the next acquisition interval.

We assume that the firm will acquire a storage capacity sufficient to meet the maximum storage needs. Furthermore, because predicting the future storage needs with 100% accuracy is difficult, we assume that the organization is likely to over-estimate its storage needs and over-provision its storage capacity to avoid a situation in which it would not be able to meet customer expectations, i.e.,

$$\hat{s}(\tau) = k_e k_s s(\tau), \tag{3.2}$$

where $k_e \geq 1$ represents an estimation error. The coefficient of redundancy, $k_s \geq 1$, is introduced to account for the fact that a portion of the storage capacity is used for purposes other than storing data — for instance, to maintain a level of redundancy sufficient for the required level of failure-resistance.

Thus, the cost of private storage in the acquisition interval, τ, can be calculated as follows:

$$c_o = k_e k_s p_o(s(\tau))s(\tau)\tau. \tag{3.3}$$

Let us now study how the length of the acquisition interval affects the total cost of a private solution.

Proposition 1. The cost of private storage increases as the length of the acquisition interval increases.

Proof. The proof of the proposition is provided in A.1. □

Proposition 1 reflects that the length of the acquisition interval positively correlates with the volume of unused or over provisioned storage. Furthermore, the demand estimation may be more inaccurate for longer acquisition intervals. Eq. (3.3) indicates that in addition to shortening the acquisition interval length, improving the demand estimation, lowering the redundancy level or decreasing the price of storage capacity also reduces the overall private storage costs.

Consider now the case of using public storage capacity. For simplicity, we will assume that the charging interval set by the public storage provider is quite small compared with the acquisition interval; for instance, the charging period is 12 h for Amazon. We can then express the length of the acquisition interval in terms of the charging intervals; for instance, monthly charging periods and yearly acquisition intervals would correspond to $\tau = 12$. Thus, the cost of public storage, c_p,

[1] http://aws-portal.amazon.com/gp/aws/developer/common/amz-storage-usage-type-help.html.

accumulated over the acquisition interval, τ, can be approximated as follows:

$$c_p = \int_1^{\tau} s(t) p_p(s(t)) dt. \tag{3.4}$$

Let us also assume that the price of a unit of public storage capacity is higher than the cost of a unit of private storage. This assumption is justified by the fact that the public storage provider charges a premium for the organization's flexibility in rapidly provisioning and de-provisioning the resources [29]; as a result, some organizations found it significantly less expensive to host their own storage facilities than to use the storage capacity of Amazon, with the difference reaching a factor of 26 [18]. Thus, the following can be rewritten: $p_p = u_s p_o$, where u_s is the utility premium ratio, or in short, the utility premium of the public storage vendor. For the sake of brevity, the prices $P_P(s(t))$ and $P_o(s(t))$ are referred to as p_p and p_o, respectively.

For simplicity, the prices are assumed to not be subject to volume discounts. Thus, Eq. (3.4) can be rewritten as follows:

$$c_p = u_s p_o \int_1^{\tau} s(t) dt. \tag{3.5}$$

To assess whether the public or private storage is less expensive, let us introduce the cost difference function, f:

$$f(\tau) = c_p - c_o = u_s p_o \int_1^{\tau} s(t) dt - k_e k_s p_o s(\tau) \tau. \tag{3.6}$$

Based on the definition, this function is positive if the private solution is cheaper than the public one, and negative if the public solution is more cost-efficient compared with the private storage.

Let us now compare the utility premium, u_s, and the product of the estimation error and redundancy level, $k_e k_s$. It follows from the discussion above that $u_s \geq 1$ and $k_e k_s \geq 1$. Assuming that i) a notable premium is charged by public storage vendors (not all organizations have the scale and capabilities required to attain a unit storage cost 26 times cheaper than Amazon, but attaining a 10-fold savings appears to be a feasible assumption), ii) the estimation error is a fraction of storage needs ($k_e < 2$), and iii) a reasonable degree of overheads is present in self-storage (e.g., $k_s < 2$), the following is likely: $u_s > k_e k_s$. Therefore, we will assume for simplicity that $u_s > k_e k_s$ [2].

Proposition 2. Given the growth demand function $s(\tau) : s(\tau) > s(1) * \tau^{\frac{u_s - k_e k_s}{k_e k_s}}$, the cost difference between public and private storage as defined by $f(\tau)$ decreases as the length of the acquisition interval increases.

Proof. The proof of the proposition is provided in A.2. □

The proposition states that the cost efficiency of public storage as compared with the private cloud increases in the length of the acquisition interval if the storage demand grows faster than the polynomial function $s(1)\tau^w$, where $w = \frac{u_s - k_e k_s}{k_e k_s} > 0$. Thus, the use of the public storage is likely to be economically justifiable when the storage demand grows rapidly and the organization's acquisition intervals are significantly longer than the charging periods of the public storage vendor. Conversely, if the storage demand grows fast and the organization can shorten the acquisition intervals to be similar to the intervals of the public storage vendor, then acquisition and maintaining of self-storage is likely to be less expensive.

[2] If $u_s \leq k_e k_s$, the cost difference between public and private storage decreases, as the length of the acquisition interval increases. This relationship can be shown by following the argumentation method that is used in the proof of Proposition 2.

Thus, the cost-efficiency of private and public storage depends on the growth profile of storage needs. In the next subsection, the cost-efficiency of private vs. public storage is analyzed for exponential, linear and logarithmic growth.

3.2. Exponential growth

In many research studies, storage demand is thought to grow exponentially, with an annual growth rate estimated as high as 70% [11,5,6]. In this case, the storage demand function can be written as follows:

$$s(t) = s(1) * g^t \tag{3.7}$$

where $g > 0$ is the storage growth rate.

Proposition 3. If the demand for storage capacity grows exponentially with time, the cost difference of public and private storage decreases as the acquisition interval length increases.

Proof. The proof of the proposition is provided in A.3. □

Thus, the cost efficiency of the private solution as compared with the public cloud decreases in the length of the acquisition time interval when the storage needs grow very rapidly. However, using the public cloud may be more economically justifiable when the organization cannot often re-assess its storage needs.

3.3. Linear growth

In some of the research papers (e.g., [27]), the storage needs were assumed to grow linearly. In this case, the storage demand function is defined as follows:

$$s(t) = s(1) + gt \tag{3.8}$$

where $g > 0$ is the growth rate.

Proposition 4. If the demand for storage capacity grows linearly with time and $\frac{u_s}{k_e k_s} \geq 2$, the cost difference between the public and private storage increases as the acquisition interval length increases.

Proof. The proof of the proposition is provided in A.4. □

Thus, the cost efficiency of private storage as compared with public storage correlates with the length of the acquisition interval if the demand for storage capacity grows linearly and storage in the public cloud is relatively expensive (e.g., without redundancy requirements and perfect storage estimation, the utility premium is greater than two). In this case, the private storage may be less expensive compared with the public cloud, especially for long acquisition intervals. However, if the public cloud is inexpensive compared with the private one, the estimation error is large, or the redundancy requirements are high, then *shortening* the acquisition interval increases the cost advantage of private storage as compared with the public solution.

3.4. Logarithmic growth

When the storage demand grows slowly and the growth can be described as a logarithm function of time, the storage demand function is defined as follows:

$$s(t) = s(1) * \ln(t). \tag{3.9}$$

Proposition 5. If the demand for storage capacity grows logarithmically with time, the cost difference between public and private storage increases as the acquisition interval length increases.

Proof. The proof of the proposition is provided in A.5. □

Thus, the cost-efficiency of public cloud as compared with the private storage decreases in the length of the acquisition interval when the storage demand grows with the inverse of the exponential growth. In other words, private storage may be less expensive compared with the public cloud despite long acquisition intervals if the storage demand grows slowly.

In the next subsection, the impact of the acquisition period length on the cost-efficiency of public vs. private storage is analyzed when data transfer costs are present.

3.5. The effect of data transfer costs

In addition to the costs of storage capacity itself, the cost of a storage solution also includes the costs incurred due to the transfer of data to and from the storage location, namely:

- the initial transfer of new data being saved (which also includes the modified versions of the previously saved items);
- the transfer of stored data back to the user in response to occasional reading requests (also including the rare retrievals of backup data).

Cheng et al. [4] analyzed the usage pattern of YouTube videos and modeled the growth of the number of views with a power-law distribution. The authors defined the active life span of the videos, stating that the videos are rarely watched again after a short period of popularity. Therefore, we will assume for the sake of simplicity that the data are intensively used shortly after they are initially saved, but only occasionally requested thereafter.

For private storage, the price of a unit of bandwidth, p_{bo}, is likely to depend on the maximum bandwidth required during the acquisition period [23]. Thus, private storage transfer costs can be estimated as a function of the maximum storage added during the acquisition period:

$$c_{bo} = k_b s(\tau) p_{bo} \tau, \tag{3.10}$$

where k_b indicates the number of times a byte of stored data is transferred on average during a period of popularity, and $s(\tau)$ is the maximum storage amount needed within the acquisition period, τ.

Conversely, the bandwidth costs when using a public storage provider are based on the actual data transfer needs within each charging period.[3] Assuming again that the volume of transferred data is proportional to the volume of data stored by the public storage provider, the cost of data transfer when using a public storage provider can be approximated as follows:

$$c_{bp} = k_b p_{bp} \int_1^\tau s(t) dt, \tag{3.11}$$

where p_{bp} is the price of a unit of bandwidth for public storage.

We assume for simplicity that the unit pricing of data communication is roughly equal to the private and the public storage ($p_{bp} \approx p_{bo}$). The private and public costs can then be defined as follows:

$$c_o = k_e k_s s(\tau) p_o \tau + k_b s(\tau) p_{bo} \tau \tag{3.12}$$

$$c_p = u_s p_o \int_1^\tau s(t) dt + k_b p_{bo} \int_1^\tau s(t) dt. \tag{3.13}$$

Proposition 6. Given the growth demand function $s(\tau) : s(\tau) > s(1) \tau^{\frac{p_o (u_s - k_e k_s)}{k_e k_s p_o + k_b p_{bo}}}$, the cost difference between public and private storage and data communications decreases as the length of the acquisition interval increases.

[3] For the simplicity of the analysis we assume that the length of the data transfer charging period is the same as the length of the storage charging period.

Proof. The proof of the proposition is provided in A.6. □

Thus, the presence of data communication costs strengthens the dependency of the cost difference and the acquisition interval length: the economic advantage of public storage as compared with private storage increases in the length of the acquisition interval when the storage needs grow sufficiently fast.

Among others, the utility premium and the length of the acquisition interval are decisive factors in the cost-efficiency of public and private storage solutions. In the next subsection, the relative sensitivity to these parameters is studied to compare their impact on the cost difference between public and private storage.

3.6. Relative sensitivity to the utility premium and the length of the acquisition interval

Let us now introduce the relative sensitivity function of the function F to the parameter α:

$$S_\alpha^f = \frac{\%change\ in\ F}{\%change\ in\ \alpha} = \frac{\frac{dF}{F}}{\frac{d\alpha}{\alpha}} = \frac{dF}{d\alpha} \frac{\alpha}{F}. \tag{3.14}$$

The relative sensitivity function, S_α^f, lets us pinpoint the values for which α has the strongest impact on the cost-efficiency of a public compared with a private solution and allows us to determine the parameters that have the greatest effect on the output for a certain percent change in the parameters [20].

Let us now calculate the relative sensitivity of the function 3.6 to the acquisition interval, S_τ^f and to the utility premium, $S_{u_s}^f$:

$$S_\tau^f = \frac{df}{d\tau} \frac{\tau}{f} = \frac{\tau \left(p_o s(\tau)(u_s - k_e k_s) - k_e k_s \tau \frac{ds}{d\tau} \right))}{u_s p_o \int_1^\tau s(t) dt - k_e k_s p_o s(\tau) \tau}, \tag{3.15}$$

and

$$S_{u_s}^f = \frac{df}{du_s} \frac{u_s}{f} = \frac{u_s p_o \int_1^\tau s(t) dt}{u_s p_o \int_1^\tau s(t) dt - k_e k_s p_o s(\tau) \tau}. \tag{3.16}$$

For example, because storage demand is considered to grow exponentially in many cases, let us specify these functions in case of exponential growth. In this case, the relative sensitivity of the cost difference function, f, to the parameter τ can be defined as S_τ^f and calculated as follows:

$$S_\tau^f = \frac{df}{d\tau} \frac{\tau}{f} = \frac{\tau \left(u_s g^\tau - k_e k_s \left(lngg^\tau \tau + g^\tau \right) \right)}{\left(u_s \frac{g^\tau - 1}{lng} - k_e k_s g^\tau \tau \right)}. \tag{3.17}$$

Conversely, the relative sensitivity of function 3.6 to the parameter u_s can be defined as $S_{u_s}^f$ and calculated as follows:

$$S_{u_s}^f = \frac{df}{du_s} \frac{u_s}{f} = \frac{u_s \frac{g^\tau - 1}{lng}}{u_s \frac{g^\tau - 1}{lng} - k_e k_s g^\tau \tau}. \tag{3.18}$$

4. Illustrative numerical examples

The previous section demonstrated that the interval at which the organization re-evaluates its storage needs and acquires additional storage capacity affects the cost-efficiency of private storage compared with public storage. Namely, for the commonly encountered exponential growth of storage demand, the acquisition interval positively correlates with the likelihood that the use of public storage is less expensive. In this section, the effect of the acquisition interval will be illustrated

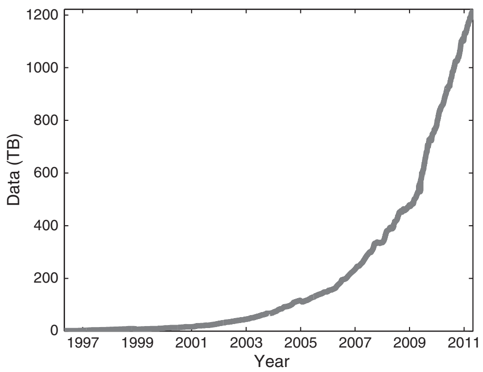


Fig. 1. Growth of the OUCS back-up and archiving storage during 1996–2011 [19].

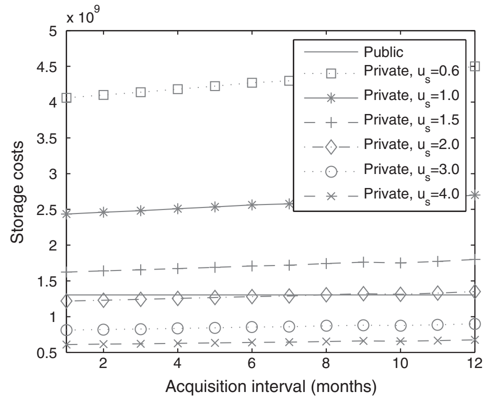


Fig. 2. Storage costs vs. acquisition intervals for different values of utility premium.

by using an example of a demand profile of the back-up and archiving service provided by Oxford University to its senior members, postgraduates, and staff members [14].

The historical traces of the growth of backup storage provided by Oxford University Computing Services (OUCS) are documented in the OUCS annual reports available at the OUCS website.[4] The growth profile over the period 1996–2011 is shown in Fig. 1. As evidenced in the figure, the demand for data storage at OUCS grew exponentially, increasing by roughly 50% on an annual basis.

With the exception of the first year of observations when a three-digit growth was recorded, the yearly increase during 1998–2011 has been below 100%; in most of the years, it fluctuated between 30% and 70%. Therefore, let us assume that the organization acquires a storage capacity sufficient for serving the maximum expected growth in the storage demand, with the maximum expected growth being 100% a year. Let us further assume that the volume of initially acquired capacity is 10 TB, that 100% of storage is reserved for redundancy purposes ($k_s = 2$), and that the additional capacity is acquired in 5 TB chunks.

In some special cases, firms need a long-term storage service from which their data is rarely retrieved, and data retrieval times of several hours are acceptable. In these scenarios, companies could utilize the Amazon Glacier Service, for example. With its extremely low storage costs, this service is most likely a cheaper alternative than the disc-based private storage solution considered in the paper, even with short acquisition intervals. However, when firms need low latency or frequent access to their data, other alternatives must be considered. Focusing on this general scenario, the unit price of the public storage can be estimated by consulting the price list of Amazon S3,[5] for example: assuming the Reduced Redundancy Storage (RRS) is used, storing the first, next 49, and next 450 TB costs $0.076, $0.064, and $0.056 per GB per month, respectively. Thus, the RRS price per TB per month is $77.82, $65.54, and $57.34 for the first TB, the next 49 TB, and the next 450 TB of data, respectively. Note that the request pricing is not considered for the sake of simplicity.

The unit price of private storage for newly designed storage solutions can be approximated using the costs incurred by Backblaze [18]: to provision a PB of storage, Backblaze reportedly spent $94,563 over three years for hardware, space, power, and bandwidth. The maintenance costs are also accounted for; according to Backblaze, an engineer maintains the company's 16 PB storage facilities. However, we consider it more realistic that an average firm, e.g., one with two datacenters, employs four engineers to provide 24/7 operations. Therefore, we assume that four engineers with a yearly salary of $44,973[6] are employed to maintain the storage capacity. This assumption results in a total cost of $634,239 per PB over three years, i.e., $17.2 per TB per month. In addition to the storage hardware, software solutions to manage the storage (such as IBM Tivoli Storage Manager) are likely to be needed, thus further increasing the cost of the storage solution; however, we will assume for the sake of simplicity that either inexpensive or open-source software is going to be used and that its costs may be neglected.

Alternatively, the unit price of private storage can be found using the charges set by the OUCS back-up and archiving service for its research project customers. According to the OUCS service level description [21], the storage cost is £842 ($1321.5) per TB per year, which results in a storage cost of £70.17 ($110.32) per TB per month.

Based on these two reference examples, the utility premium, u_s, may vary depending on the cost-efficiency of the private solution: for example, the premium varies from $61.56/$110.32 = 0.58 (OUCS) to $61.56/$17.2=3.58 (Backblaze) per TB per month for 100 TB of storage. Therefore, we will explore a set of different values of $u_s = \{0.6;1.0;1.5;2.0;3.0;4.0\}$.

The above cost estimates consider neither the gradual price decline nor the effect of the net present value of the assets. Both of these factors are important and affect the total cost of the storage solution; however, as their effect has been studied elsewhere [27], we have decided to exclude these factors from the analysis in this study to focus on and better illuminate the effect of the acquisition interval on the total costs.

In Fig. 2, the total costs of private and public storage solutions that accumulated over the period from 1996–2011 are compared for different levels of the utility premium, u_s. The figure shows that the private storage cost increases along with the storage acquisition interval. Given the utility premium value, $u_s \leq 1.5$, the total cost of private storage always exceeds the cost of public storage, which is in line with the analysis in [29]. Conversely, given $u_s \leq 2.0$, private storage is less expensive when the acquisition interval is short, but becomes more expensive than public storage as the length of the interval grows, which supports the analytical reasoning presented earlier in Section 3.1 (cf. Proposition 2).

[4] Available at http://www.oucs.ox.ac.uk/internal/annrep/.

[5] Available at http://aws.amazon.com/s3/; prices used in the research are valid on 3.6.2013.

[6] Based on http://swz.salary.com/SalaryWizard/Installation-Maintenance-Technician-I-HRSalary-Details.aspx.

In addition, we further investigated the cost savings attributed to the decrease of the acquisition interval length compared with the overall costs. Let us now consider the private cost saving function, r:

$$r(a) = 1 - \frac{c_o^a}{c_o^{12}}, \qquad (4.1)$$

where α is the acquisition interval length in number of months, c_o^a is the total private storage cost with acquisition interval length α, and c_o^{12} is the total private storage cost when the acquisition interval is one year long. The function clearly indicates that private cost savings are independent of the price, estimation error, and redundancy level. By calculating the values of this function, we have found that the total costs of a private solution can be reduced by approx. 20% by decreasing the length of the acquisition interval from one year to one month.

Fig. 3 shows the relative sensitivity functions S_τ^f and $S_{u_s}^f$ (defined in Eq. (3.6)) for $u_s = 2$. The picture shows that the acquisition interval length has the strongest impact when it is near eight months for $u_s = 2$, which agrees with Fig. 2. The figure also shows that the utility premium has a greater (smaller) effect on the cost difference function compared with the effect of the acquisition interval if the acquisition interval is shorter (longer) than eight months.

The cumulative effect of the acquisition interval and the level of redundancy on the storage cost are illustrated in Fig. 4. The increase in the required redundancy shortens the acquisition interval for which the private storage remains cost-efficient. Furthermore, for a redundancy above a certain threshold (2.2 in this example), the cost of private storage always exceeds the public storage cost even for the shortest interval.

The sum of the storage and data communication costs is portrayed in Fig. 5 as a function of the acquisition interval. The figure shows that the intensity of data communications (manifested in the value of k_b) has an effect similar to the effect of the level of redundancy: namely, the greater the volume of data transfer incurred due to storing the data, the shorter the acquisition intervals that need to be maintained for the private storage to remain less expensive than the public storage. These findings agree with the analytical reasoning presented earlier in Section 3.5 (cf. Proposition 6).

Furthermore, Fig. 6 illustrates how the estimation errors can be compensated with shorter acquisition intervals. For example, given the estimation error $k_e = 1.6$, an acquisition interval shorter than six months is needed to ensure that private storage is cheaper than the public solution. Furthermore, if the storage demand is well known

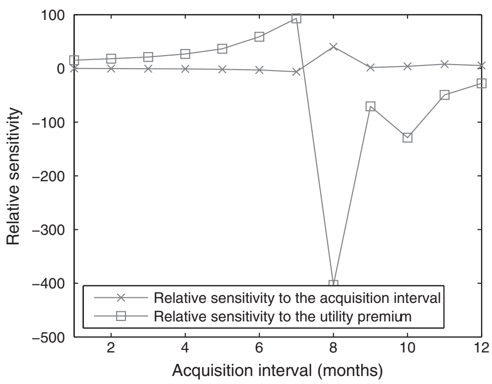


Fig. 3. Relative sensitivity to the utility premium and acquisition interval when $u_s = 2$.

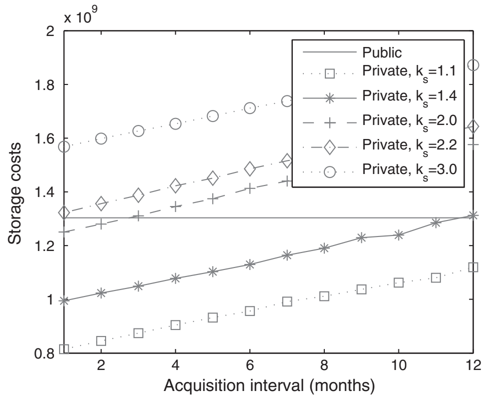


Fig. 4. Storage costs vs. acquisition intervals for different levels of redundancy.

($k_e \approx 1$), the private solution is more cost-efficient than the public solution. Conversely, if the needs are not easily estimable, the public solution is the cheaper alternative.

5. Discussion

One of the benefits of adopting public cloud infrastructure is the possibility to provision the required infrastructure resources instantly as the demand for the resources increases instead of acquiring them in advance. This on-demand provisioning minimizes the time during which the resources are idle and therefore allows the related costs to be reduced. This benefit is particularly important in case of storage resources, where the demand is steadily or rapidly increasing rather than fluctuating.

The cost benefit of on-demand storage provisioning depends greatly on whether (and how much) the private storage acquisition interval is longer than the charging period of the public cloud storage, which was analytically shown in the paper. In particular, for the commonly encountered exponential growth of storage demand, the use of private storage is likely to become more cost-efficient than the use of public cloud storage when the storage acquisition interval shortens and approaches the public cloud charging period. Because the acquisition interval is determined by the organization's ability to foresee the

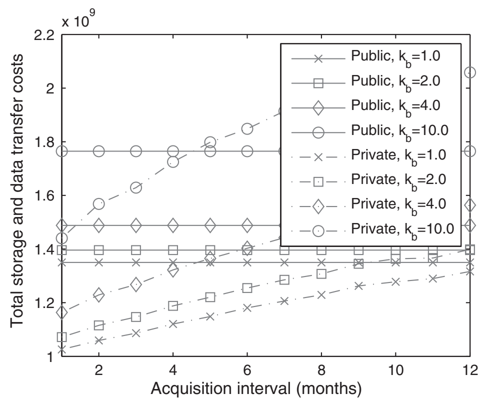


Fig. 5. Storage and data transfer costs vs. acquisition intervals for different levels of data communication intensity.

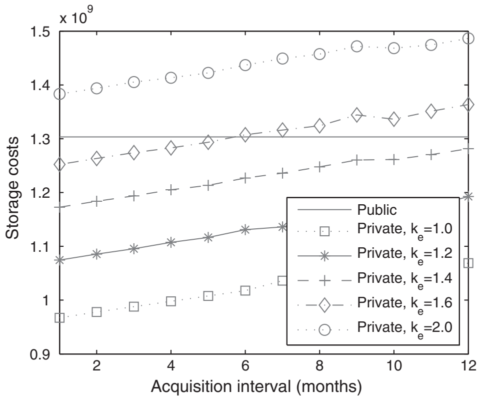


Fig. 6. Storage and data transfer costs vs. acquisition intervals for different estimation error levels.

growth of storage demand, by the provisioning schedules of storage equipment providers and the internal practices of the organization (among other factors), an organization that owns a private storage solution may want to control some of these factors to attain a shorter acquisition interval and thus make the private storage (more) cost-efficient. Conversely, if controlling these factors is challenging in practice, the organization may find it justifiable from a cost perspective to switch to using the public cloud storage.

The effect of the acquisition interval is further compounded by the effect of the data transfer costs that are incurred when transmitting the data to and from the cloud. Assuming that the charging model for the data transfer in the private infrastructure is based on the maximum traffic within the charging period and the storage demand grows quickly, the data transfer costs may make the private storage more expensive and hence may make public storage cost-beneficial even for shorter acquisition intervals.

The organizations were assumed to over-provision the storage capacity in the paper to guarantee that the customer expectations are met. In some application, these guarantees may be relaxed, i.e. the provisioning of the storage may be delayed until the next acquisition time without incurring penalties. However, from the perspective of the presented cost model, such delays can be considered to shorten the acquisition intervals by the value of the tolerated delay in storage provisioning.

Furthermore, the cloud providers were assumed to charge their customers based on the maximum storage usage within a charging period in the paper, which is in line with Amazon S3 or Windows Azure Storage pricing. While Amazon measures the actual storage at least twice a day, Microsoft measures it at least daily.[7] Although the paper contains the results of calculations with a 12 h charging period (in line with Amazon's pricing model), the results of the analysis remain the same even with different charging interval lengths or lower prices set by the public storage provider. Conversely, storage providers may also apply other pricing models that may change the analysis slightly. However, exploring the effect of other alternative pricing models on the cost-efficiency of the private vs. public storage was left for further studies because of space limitations.

Finally, the analysis in the paper assumes that the cost of a unit of private storage capacity is less than that of a unit price of public cloud storage. Moreover, the cost of a unit of capacity is likely to be significantly lower for public cloud infrastructure providers [7] due to the economies of scale exercised by them when acquiring and managing their resources. In the future, cloud infrastructure providers may have to decrease their pricing as a result of competitive forces, thus making the unit cost of private storage exceed the unit price of public storage. Should this scenario materialize, the use of public cloud storage will become advantageous from a cost perspective, even if the private storage acquisition intervals are short. For example, the Amazon Glacier data-archiving service may provide resources for rarely accessed data with lower costs than a private solution with short acquisition intervals. However, companies that utilize this service should accept some restrictions, such as slow data retrieval and possible additional costs for early or frequent data retrieval.

6. Conclusions

Contemporary organizations need to cope with the rapidly growing demand for data storage. When deciding on the approach to meet the increasing storage needs, these organizations may choose to build and manage private data storage facilities or utilize the on-demand storage services offered by the providers of public cloud infrastructure. The comparative cost-efficiency of these two alternatives depends on a number of factors, such as the pricing difference between public and private storage, the charging period (for the public storage) and the storage acquisition interval (for the private storage), the storage growth profile and the predictability of the demand for storage.

In this paper, an analytical tool was introduced to support an organization's assessment of the cost-efficiency of a private vs. a public storage solution. This study analytically showed that when assuming a fast growth in storage needs, e.g., currently common exponential growth, the use of public storage is likely to be more cost-efficient for organizations with relatively long acquisition cycles, e.g., once per year. Conversely, should the organization have a possibility to reassess its storage needs and acquire additional storage often—say, every second month—the use of private storage capacity is likely to prove less expensive. The analysis shows also that in case storage demand grows slowly, for example logarithmically, the inverse regularity is observed; namely, private storage becomes more cost-efficient as the acquisition intervals grow longer.

The paper also illustrated that other factors in addition to the acquisition interval, such as the utility premium charged by the public storage provider, the level of needed storage redundancy, the estimation error, and the incurred data communications, have a compound effect on the cost efficiency of the private vs. public storage. More specifically, a decline in the utility premium, an increase in the storage redundancy, or an increase in the estimation error shorten the maximum length of the acquisition interval that can be allowed for the private storage to be less expensive compared with the public storage.

Private storage is likely to be more cost efficient for short acquisition intervals, assuming that the capacity growth is relatively easy to estimate or the data retrieval can cause intensive but steady communication with the data storage. The cloud alternative is well-justified if the organization is not sufficiently large to enjoy rather similar pricing of equipment and communication capacity compared with large cloud data centers or the organization does not have resources or competence to run an in-house data center. Thus, the use of public cloud storage is a likely option when launching new services in small and growing organizations that have new services whose market adoption is difficult to estimate. For mature services, the storage load is easier to estimate based on the historical data, while insourcing the storage will be difficult due to the excessive cost of transferring data from public cloud storage to an in-house data center.

In further work, the proposed approach could be extended in several directions. First, the time dimension of the analytical tool shall be expanded to account for the declining pricing trends, and the pricing

[7] http://aws-portal.amazon.com/gp/aws/developer/common/amz-storage-usage-type-help.html;http://blogs.msdn.com/b/windowsazurestorage/archive/2010/07/09/understanding-windows-azure-storage-billing-bandwidth-transactions-and-capacity.aspx.

estimates themselves could be revised to include visible volume discounts e.g., in Amazon AWS offerings, as well as additional incurred costs, such as the costs of input–output requests. In addition to a deterministic storage growth profile, probabilistic profiles could be studied in future works. For a more holistic view, probabilistic communication patterns should also be considered. Finally, the specifics of possible organization's architectural solutions could be explored when estimating the data communication overheads, because they may significantly influence the data communication costs.

Acknowledgment

This work was supported by TEKES as part of the Cloud Software Program of DIGILE (Finnish Strategic Centre for Science, Technology and Innovation in the field of ICT and digital business).

Appendix A. Proofs of the propositions

A.1. Proof of the Proposition 1

Proof. Let us take the derivative of the function c_o:

$$\frac{dc_o}{d\tau} = k_e k_s p_o \left(\frac{ds(\tau)}{d\tau}\tau + s(\tau)\right). \quad \text{(A.1)}$$

Because the storage demand is increasing over time, we know that $\frac{ds(\tau)}{d\tau}>0$. Furthermore, k_e, k_s, p_o, $s(\tau)$ and τ are all positive. Thus, the derivative of the private cost function, c_o, with respect to τ is positive. The function monotonically increases with the increase of the acquisition interval, i.e. the longer the acquisition interval, the more expensive the private solution is. □

A.2. Proof of the Proposition 2

Proof. The correctness of the proposition can be shown by taking derivative of function 3.6 and applying the fundamental theorem of calculus:

$$\begin{aligned}\frac{df}{d\tau} &= p_o u_s s(\tau) - p_o k_e k_s \left(\frac{ds}{d\tau}\tau + s(\tau)\right)\\ &= p_o\left(s(\tau)(u_s - k_e k_s) - k_e k_s \frac{ds(\tau)}{d\tau}\tau\right).\end{aligned} \quad \text{(A.2)}$$

Let us denote the ratio $a = \frac{k_e k_s}{u_s - k_e k_s} > 0$. Because the unit price, p_o, is positive,

$$\frac{df}{d\tau} < 0 \Leftrightarrow s(\tau) - a\tau \frac{ds(\tau)}{d\tau} < 0. \quad \text{(A.3)}$$

The differential inequality A.3 is a Gronwall's inequality. Let us now define the functions

$$\beta(\tau) = \frac{1}{\tau a} \quad \text{(A.4)}$$

and

$$v(\tau) = e^{\int_1^\tau \beta(t)dt}, \quad \text{(A.5)}$$

where $v(\tau) > 0$ and $v(1) = 1$.

With these denotations, inequality A.3 can be rewritten in the following form:

$$\frac{ds(\tau)}{d\tau} > \beta(\tau)s(\tau). \quad \text{(A.6)}$$

Note that

$$\frac{dv(\tau)}{d\tau} = e^{\int_1^\tau \beta(t)dt}\frac{1}{\tau a} = \beta(\tau)v(\tau) \quad \text{(A.7)}$$

and

$$\frac{d\frac{s(\tau)}{v(\tau)}}{d\tau} = \frac{\frac{ds(\tau)}{d\tau}v(\tau) - \frac{dv(\tau)}{d\tau}s(\tau)}{v^2(\tau)}. \quad \text{(A.8)}$$

We obtain the following by applying inequality A.6 to A.8:

$$\frac{d\frac{s(\tau)}{v(\tau)}}{d\tau} > \frac{\beta(\tau)s(\tau)v(\tau) - \beta(\tau)v(\tau)s(\tau)}{v^2(\tau)} = 0. \quad \text{(A.9)}$$

Applying the mean value theorem, it follows that

$$\frac{s(\tau)}{v(\tau)} > \frac{s(1)}{v(1)} = s(1), \quad \text{(A.10)}$$

thus,

$$s(\tau) > s(1)e^{\int_1^\tau \frac{1}{\tau a}d\tau}. \quad \text{(A.11)}$$

Because

$$e^{\int_1^\tau \frac{1}{\tau a}d\tau} = e^{\frac{1}{a}ln\tau} = e^{(ln\tau)^{\frac{1}{a}}} = \tau^{\frac{1}{a}}, \quad \text{(A.12)}$$

it follows that the cost difference function, *f*, decreases when

$$s(\tau) > s(1)\tau^{\frac{u_s - k_e k_s}{k_e k_s}}. \quad \text{(A.13)}$$

□

A.3. Proof of the Proposition 3

Proof. Eq. (3.6) takes the following form for exponential growth:

$$f = u_s p_o s(1)\frac{g^\tau - g}{lng} - k_e k_s p_o s(1) g^\tau \tau. \quad \text{(A.14)}$$

Let us now take the derivative of the cost difference function:

$$\begin{aligned}\frac{df}{d\tau} &= u_s p_o s(1) g^\tau - k_e k_s p_o s(1)\left(lng\ g^\tau \tau + g^\tau\right)\\ &= g^\tau p_o\ \ s(1)(u_s - k_e k_s lng\tau - k_e k_s).\end{aligned} \quad \text{(A.15)}$$

Because $p_o > 0$, $s(1) > 0$, and $g^\tau > 0$, derivative A.15 is negative if $u_s - k_e\ k_s \ln g\ \tau - k_e\ k_s < 0$. Thus, the cost difference function decreases, if

$$\tau > \frac{u_s - k_e k_s}{\ln(g) k_e k_s}. \quad \text{(A.16)}$$

The ratio $\frac{u_s - k_e k_s}{\ln(g) k_e k_s}$ is likely to be a small constant (e.g., for realistic values $u_s = 10$, $k_e = 2$, $k_s = 2$, and $g = 2$, the value of the ratio is 2.16, which indicates a one day-long acquisition interval for 12 h public charging period), below which the acquisition interval length cannot be reasonably shortened further. Thus, the cost difference between public and private storage decreases with the growth of the acquisition interval for exponential growth.

□

A.4. Proof of the Proposition 4

Proof. The cost difference function is defined as follows when the storage needs grow linearly with time:

$$f(\tau) = u_s p_o \left(s(1)\tau + g\frac{\tau^2}{2} - s(1) - \frac{g}{2} \right) - k_e k_s p_o \tau (s(1) + g\ \tau). \quad (A.17)$$

Let us take the derivative of function A.17 with respect to the acquisition interval, τ:

$$\frac{df}{d\tau} = p_o(\tau g (u_s - 2 k_e k_s) + s(1)(u_s - k_e k_s)). \quad (A.18)$$

Let us now denote the ratio $q = \frac{u_s}{k_e k_s} > 0$. Because $p_o > 0$, function A.17 increases if derivative A.18 is positive. Thus, A.17 increases when

$$\tau g (q-2) + s(1)(q-1) > 0. \quad (A.19)$$

Let us now consider the following cases:

- If $q \geq 2$ then A.19 is true because $\tau > 0, g > 0$ and $s(1) > 0$. Thus, the function A.17 monotonically increases in this case.
- If $1 < q < 2$, function A.17 increases if

$$\tau < -\frac{s(1)}{g}\frac{q-1}{q-2}. \quad (A.20)$$

- If $q \leq 1$ then inequality A.19 cannot be satisfied because $\tau > 0, g > 0$ and $s(1) > 0$.

In summary, the function monotonically increases if $\frac{u_s}{k_e k_s} \geq 2$, or if $1 < \frac{u_s}{k_e k_s} < 2$ and $\tau < -\frac{s(1)}{g}\frac{u_s - k_e k_s}{u_s - 2 k_e k_s}$. □

A.5. Proof of the Proposition 5

Proof. The cost difference function takes the following form for logarithmic growth:

$$f(\tau) = u_s p_o s(1)(\tau \ln\tau - \tau - 1) - k_e k_s p_o s(1) \ln\tau\ \tau. \quad (A.21)$$

We obtain the following by taking the derivative of the function:

$$\begin{aligned} \frac{df(\tau)}{d\tau} &= p_o s(1)(u_s \ln\tau - k_e k_s - k_e k_s \ln\tau) \\ &= p_o s(1)((u_s - k_e k_s)\ln\tau - k_e k_s). \end{aligned} \quad (A.22)$$

The cost difference function increases when derivative 41 is positive. Because $p_o > 0$ and $s(1) > 0$, and because of the assumption $u_s > k_e k_s$, the derivative is positive when

$$\tau > e^{\frac{k_e k_s}{u_s - k_e k_s}}. \quad (A.23)$$

Because $e^{\frac{k_e k_s}{u_s - k_e k_s}}$ is a small constant, the cost difference function monotonically increases for reasonable acquisition interval lengths. □

A.6. Proof of the Proposition 6

Proof. Let us define the cost-ratio function, f:

$$\begin{aligned} f(\tau) &= c_p - c_o \\ &= (u_s p_o + k_b p_{bo}) \int_1^\tau s(t)dt - (k_e k_s s(\tau) p_o \tau + k_b s(\tau) p_{bo}\ \tau). \end{aligned} \quad (A.24)$$

Let us now take the derivative of function A.24 with respect to the acquisition interval, τ:

$$\frac{df}{d\tau} = (u_s p_o + k_b p_{bo}) s(\tau) - (k_e k_s p_o + k_b p_{bo}) \left(\frac{ds(\tau)}{d\tau}\tau + s(\tau) \right). \quad (A.25)$$

$$= (u_s p_o - k_e k_s\ p_o) s(\tau) - (k_e k_s p_o + k_b p_{bo}) \tau \frac{ds(\tau)}{d\tau}. \quad (A.26)$$

Because of assumption $u_s > k_e k_s$, we will denote the ratio $a = \frac{k_e k_s p_o + k_b p_{bo}}{p_o (u_s - k_e k_s)} > 0$.

Derivative A.25 is negative if

$$s(\tau) - a\tau \frac{ds(\tau)}{d\tau} < 0. \quad (A.27)$$

Inequality A.27 is the same Gronwall's inequality as A.3 and can be solved by following the same steps. Thus, the cost difference function decreases when

$$s(\tau) > s(1)\tau^{\frac{p_o (u_s - k_e k_s)}{k_e k_s p_o + k_b p_{bo}}}. \quad (A.28)$$

If the storage needs grow relatively quickly, the function monotonically decreases as the acquisition interval increases, i.e., the cost-efficiency of the public cloud as compared with the private solution increases in the length of the acquisition interval.

References

[1] I.F. Adams, D.D. Long, E.L. Miller, S. Pasupathy, M.W. Storer, Maximizing efficiency by trading storage for computation, in: Proc. of the Workshop on Hot Topics in Cloud Computing (HotCloud).
[2] A. Benlian, T. Hess, Opportunities and risks of software-as-a-service: findings from a survey of it executives, Decision Support Systems 52 (2011) 232–246.
[3] C. Bodenstein, M. Hedwig, D. Neumann, in: D.F. Galletta, T.P. Liang (Eds.), Strategic Decision Support for Smart-Leasing Infrastructure-As-A-Service, ICIS, Association for Information Systems, 2011.
[4] X. Cheng, C. Dale, J. Liu, Statistics and social network of youtube videos, Quality of Service, 2008. IWQoS 2008. 16th International Workshop on, 2008, pp. 229–238.
[5] J. Gantz, D. Reinsel, Extracting value from chaos, IDC iView, available from http://idcdocserv.com/11422011(last retrived on 29.2.2012).
[6] F. Gens, IDC Predictions 2012: Competing for 2020, Report, IDC, 2011.
[7] J. Hamilton, Cloud computing economies of scale, MIX10, 2010.
[8] M. Hedwig, S. Malkowski, C. Bodenstein, D. Neumann, Datacenter investment support system (daisy), Proceedings of the 2010 43rd Hawaii International Conference on System Sciences, HICSS '10, IEEE Computer Society, Washington, DC, USA, 2010, pp. 1–10.
[9] A. Khajeh-Hosseini, D. Greenwood, J.W. Smith, I. Sommerville, The cloud adoption toolkit: supporting cloud adoption decisions in the enterprise, Software: Practice and Experience—Special Issue on Software Architectures and Application Development Environments for Cloud Computing, 2011.
[10] A. Khajeh-Hosseini, D. Greenwood, J.W. Smith, I. Sommerville, The cloud adoption toolkit: supporting cloud adoption decisions in the enterprise, Software: Practice and Experience 42 (2012) 447–465.
[11] L. Mastroeni, M. Naldi, Long-range evaluation of risk in the migration to cloud storage, Commerce and Enterprise Computing (CEC), 2011 IEEE 13th Conference on, 2011, pp. 260–266.
[12] O. Mazhelis, P. Tyrväinen, Economic aspects of hybrid cloud infrastructure: user organization perspective, Information Systems Frontiers (2011) 1–25.
[13] O. Mazhelis, P. Tyrväinen, Role of data communications in hybrid cloud costs, in: Proceedings of the 37th EUROMICRO Conference on Software Engineering and Advanced Applications.
[14] C. Morris, Data Backup and Archiving on the HFS, Oxford University Computing Services, 2011. (available from http://www.oucs.ox.ac.uk/hfs/, last retrived on 23.2.2012).
[15] K.K. Muniswamy-Reddy, P. Macko, M. Seltzer, Making a cloud provenance-aware, in: 1st Workshop on the Theory and Practice of Provenance.

[16] K.K. Muniswamy-Reddy, P. Macko, M. Seltzer, Provenance for the cloud, in: Proceedings of the 8th USENIX conference on File and storage technologies, USENIX Association, pp. 15–14.
[17] K.K. Muniswamy-Reddy, M. Seltzer, Provenance as first class cloud data, ACM SIGOPS, Operating Systems Review 43 (2010) 11–16.
[18] T. Nufire, Petabytes on a budget v2.0: Revealing more secrets, Backblaze blog, available from http://blog.backblaze.com/2011/07/20/petabytes-on-a-budget-v2-0revealing-more-secrets/2011(last retrived on 15.2.2012).
[19] OUCS, OUCS Annual Report 2004–2005, Oxford University Computing Services, 2006, (available from http://www.oucs.ox.ac.uk/internal/annrep/annrep0405/, last retrived on 23.2.2012).
[20] E.D. Smith, F. Szidarovszky, W.J. Karnavas, A.T. Bahill, Sensitivity analysis, a powerful system validation technique, Open Cybernetics and Systemics Journal 2 (2008) 39–56.
[21] I. Smith, M. Fraser, Service Level Description: Back-up and Archiving Service (HFS), Oxford University Computing Services, 2011. (available from http://www.oucs.ox.ac.uk/internal/sld/hfs.xml, last retrived on 23.2.2012).
[22] G. Stigler, The economies of scale, Journal of Law and Economics 1 (1958) 54–71.
[23] B. Stiller, P. Reichl, S. Leinen, Pricing and cost recovery for internet services: practical review, classification and application of relevant models, NETNOMICS 3 (2001).
[24] J. Strebel, A. Stage, An economic decision model for business software application deployment on hybrid cloud environments, in: M. Schumann, L.M. Kolbe, M.H. Breitner, A. Frerichs (Eds.), Multikonferenz Wirtschaftsinformatik, Universittsverlag Gttingen, 2010, p. 195206.
[25] I. Trummer, F. Leymann, R. Mietzner, W. Binder, Cost-optimal outsourcing of applications into the clouds, Cloud Computing Technology and Science (CloudCom), 2010 IEEE Second International Conference on, 2010, pp. 135–142.
[26] S. Uttamchandani, K. Voruganti, R. Routray, L. Yin, A. Singh, B. Yolken, Brahma: planning tool for providing storage management as a service, IEEE International Conference on Services Computing (SCC 2007), 2007, pp. 1–10.
[27] E. Walker, W. Brisken, J. Romney, To lease or not to lease from storage clouds, Computer 43 (2010) 44–50.
[28] J. Weinman, Cloudonomics: a rigorous approach to cloud benefit quantification, The Journal of Software Technology 14 (2011) 10–18.
[29] J. Weinman, Mathematical proof of the inevitability of cloud computing, Working paper, 2011, (available from http://www.joeweinman.com last retrieved on February 28, 2012).
[30] J. Weinman, Time is money: the value of "on-demand", Working paper, 2011, (available from http://http://www.joeweinman.com last retrieved on February 28, 2012).
[31] D. Yuan, Y. Yang, X. Liu, J. Chen, A cost-effective strategy for intermediate data storage in scientific cloud workflow systems, Parallel & Distributed Processing (IPDPS), 2010 IEEE International Symposium on, IEEE, 2010, pp. 1–12.
[32] D. Yuan, Y. Yang, X. Liu, J. Chen, On-demand minimum cost benchmarking for intermediate dataset storage in scientific cloud workflow systems, Journal of Parallel and Distributed Computing 71 (2011) 316–332.
[33] D. Yuan, Y. Yang, X. Liu, G. Zhang, J. Chen, A data dependency based strategy for intermediate data storage in scientific cloud workflow systems, Concurrency and Computation: Practice and Experience 24 (2010) 956–976.

Gabriella Laatikainen is a PhD student at the Department of Computer Science and Information Systems, University of Jyväskylä, Finland. She received a degree of MSc. Mathematics and Computer Science from University of Debrecen, Hungary in 2007. Her research interests include cloud services, software pricing, business models in IT services industry.

Oleksiy Mazhelis is a post-doc researcher at the Department of Computer Science and Information Systems, University of Jyväskylä, Finland. He received a degree of MSc (Specialist) from Kharkov National University of Radio-Electronics, Ukraine in 1997, and received his licentiate and doctoral degrees from the University of Jyväskylä in 2004 and 2007, respectively. Starting from 2004, he was working in various research projects conducted in collaboration with industrial partners. His current research interests encompass techno-economics, systems analysis, machine learning, and pattern recognition, applied to the domains of software industry evolution, internet-of-things, telecommunications and cloud software, as well as intelligent transportation systems.

Pasi Tyrväinen is Professor of Information Systems and vice Dean at the Faculty of IT at the University of Jyväskylä. He received his doctoral degree at Helsinki University of Technology in 1994 and is a member of IEEE, ACM and AoM. His previous affiliations include R&D management positions at Honeywell Industrial Control and Nokia Research Center. His research interests include enterprise content management, cloud services and software business, and studies in these areas laid the ground for establishing the ICSOB conference series on software business research in 2010. On these subjects he has written several books and published numerous articles both in business and engineering management journals.

V

COST BENEFITS OF FLEXIBLE HYBRID CLOUD STORAGE: MITIGATING VOLUME VARIATION WITH SHORTER ACQUISITION CYCLE

by

Gabriella Laatikainen, Oleksiy Mazhelis & Pasi Tyrväinen, 2016

Journal of Systems and Software, vol. 122, pp. 180-201

The Journal of Systems and Software 122 (2016) 180–201

Contents lists available at ScienceDirect

The Journal of Systems and Software

journal homepage: www.elsevier.com/locate/jss

Cost benefits of flexible hybrid cloud storage: Mitigating volume variation with shorter acquisition cycle

Gabriella Laatikainen[a,*], Oleksiy Mazhelis[a], Pasi Tyrvainen[b]

[a] University of Jyvaskyla, Department of Computer Science and Information Systems, P.O. Box 35, FI-40014 University of Jyvaskyla, Finland
[b] University of Jyvaskyla, Agora Center, P.O. Box 35, FI-40014 University of Jyvaskyla, Finland

ARTICLE INFO

Article history:
Received 23 September 2015
Revised 3 May 2016
Accepted 3 September 2016
Available online 13 September 2016

Keywords:
Hybrid cloud storage
Volume variation
Reassessment interval
Acquisition interval
Plural governance
Concurrent sourcing

ABSTRACT

Hybrid cloud storage combines cost-effective but inflexible private storage along with flexible but premium-priced public cloud storage. As a form of concurrent sourcing, it offers flexibility and cost benefits to organizations by allowing them to operate at a cost-optimal scale and scope under demand volume uncertainty. However, the extant literature offers limited analytical insight into the effect that the non-stationarity (i.e., variability) and non-determinism (i.e., uncertainty) of the demand volume – in other words, the demand variation – have on the cost-efficient mix of internal and external sourcing. In this paper, we focus on the reassessment interval – that is, the interval at which the organization re-assesses its storage needs and acquires additional resources –, as well as on the impacts it has on the optimal mix of sourcing. We introduce an analytical cost model that captures the compound effect of the reassessment interval and volume variation on the cost-efficiency of hybrid cloud storage. The model is analytically investigated and empirically evaluated in simulation studies reflecting real-life scenarios. The results confirm that shortening the reassessment interval allows volume variability to be reduced, yielding a reduction of the overall costs. The overall costs are further reduced if, by shortening the interval, the demand uncertainty is also reduced.

1. Introduction

The multi-faceted phenomenon of cloud computing brings together technological advances in areas such as hardware virtualization, networking, and multi-tenancy and blends them into highly flexible shared computing resources that are accessible by multiple customers over the Internet (Babcock, 2010; Armbrust et al., 2010). The emergence of cloud computing has changed the way organizations purchase information technology (IT), as well as the role the IT function has in organizations, especially with respect to enabling innovativeness and creating new networked business models (Weinhardt et al., 2009; Schlagwein et al., 2014). At the core of cloud computing's multiple impacts lies the flexibility of shared computing capacity and the related decrease in capital expenditures that are enabled by, among other factors, the decreased cost of communicating with external cloud computing and storage systems (Mazhelis and Tyrväinen, 2012; Chen and Wu, 2013). Without this flexibility to utilize cloud-based capacity, the transformation of the IT function and the emergence of innovative networked models would be unlikely to succeed (Venters and Whitley, 2012; Schlagwein et al., 2014).

Hybrid cloud infrastructure, where there is a combination of concurrently used private and public cloud infrastructure resources (Armbrust et al., 2010), offers further flexibility as well as cost savings (Mazhelis and Tyrväinen, 2012). In this context, the public cloud refers to the computing, storage, and other infrastructure resources provided publicly by an infrastructure service provider to any organization willing to use these resources, on demand, over the Internet (Mell and Grance, 2011). These infrastructure service providers often charge for the use of their resources based on the real volume of usage. Whereas the pricing for small–scale use is competitive, especially for small enterprises lacking IT competences, the high profit margins of the infrastructure providers (Gauger, 2013) may make their services overly expensive for larger enterprises.

Cloud computing, as a form of on-demand computing, represents a special form of outsourcing (Willcocks and Lacity, 2012; Venters and Whitley, 2012; Chen and Wu, 2013; Son et al., 2014), whereby the property or decision rights regarding the IT infrastructure are transferred to an external organization. Furthermore, the hybrid cloud infrastructure can be seen as an instantiation of concurrent sourcing, which is a simultaneous use of market con-

* Corresponding author.
E-mail addresses: gabriella.laatikainen@jyu.fi (G. Laatikainen), mazhelis@jyu.fi (O. Mazhelis), pasi.tyrvainen@jyu.fi (P. Tyrvainen).

http://dx.doi.org/10.1016/j.jss.2016.09.008

tracting and vertical integration, that is, a situation in which the same good or service is produced as well as bought(Parmigiani, 2007; Parmigiani and Mitchell, 2009; Mols, 2010; Heide et al., 2013).

Outsourcing and make-or-buy decisions have been the subject of extensive study in the field of information systems (IS) (Gregory et al., 2013; Lacity et al., 2011; Kotlarsky et al., 2014), as well as in strategic management and operations management research (Freytag and Kirk, 2003; van de Water and van Peet, 2006; Weigelt and Sarkar, 2012). Along with the need to focus on core capabilities, cost-savings represent the most frequently cited reasons behind the decisions to outsource in general (Lacity et al., 2009), and the decision to use public cloud infrastructure in particular (Venters and Whitley, 2012).

Meanwhile, hybrid cloud infrastructure as a concurrent sourcing phenomenon has attracted little attention from the IS research community. Whereas concurrent sourcing has been widely studied outside of IS in the automotive (Gulati et al., 2005), metal forming (Parmigiani, 2007) and fashion garments industries (Jacobides and Billinger, 2006), to the best knowledge of the authors, the paper by Mazhelis and Tyrväinen (2012) is the only work where the hybrid cloud infrastructure is discussed as an instantiation of concurrent sourcing. Therefore, research inquiry into cloud-enabled flexibility, and in particular into the hybrid cloud and its impact on future cloud services, has been indentified as one of the directions for further research (Venters and Whitley, 2012).

Concurrent sourcing has been studied from the viewpoint of theories such as transaction cost economics, agency theory, resource-based theory, neoclassical economics, life cycle theory, resource and capability view, theories of multi-profit center firms, marketing channels, options theory, and knowledge-based theory (Mols, 2010; Mols et al., 2012). A widely cited justification for the use of concurrent sourcing derives from transactional cost theories and neoclassical economics. Specifically, it is claimed that this form of governance reduces production costs when firms face so-called volume uncertainty (Adelman, 1949; Parmigiani, 2003; Mols, 2010), that is, difficulty in accurately predicting demand volumes (Parmigiani, 2003; 2007). When the demand is fluctuating and it is difficult to forecast it accurately, the risk of diseconomies of scale due to unutilized excess capacity may be mitigated by serving the high probability component of demand with in-house resources and by using external suppliers for the peak demand only (Heide, 2003; Puranam et al., 2013). Thus, the degree of uncertainty has an impact on how much to produce internally versus how much to procure from external sources, and it determines the volume of cost savings that are attainable by sourcing concurrently. However, the empirical results on whether the use of concurrent sourcing is motivated by the presence of volume uncertainty are contradictory (Parmigiani, 2003; Krzeminska et al., 2013).

It has been observed that volume uncertainty reflects the difficulty in accurately predicting demand volumes and can be defined as the degree of (in)precision with which volume is predicted (Parmigiani, 2003; 2007). However, besides this prediction inaccuracy, the natural variation in the volume of the demand referred to as *variability* (e.g., seasonal fluctuations) can be the reason for the diseconomies of scale in case the firm decides to invest in production for the peak demand (Puranam et al., 2013). Note that, in principle, this natural variation may be fully deterministic and perfectly predictable. Together, the volume uncertainty and volume variability comprise the *variation* in the volume of the demand (van Belle, 2008). To the best knowledge of the authors, the variability aspect of variation has not been explicitly considered in the concurrent sourcing literature.

A key question in the recent literature on cloud computing as well as on concurrent sourcing is the optimal mix of internal and external sourcing. Indeed, the cost-optimal mix of private and public cloud resources has been one of the crucial themes in cloud computing literature, predominantly focusing on the dynamic allocation of available resources (Trummer et al., 2010; Shifrin et al., 2013; Wang et al., 2013; Altmann and Kashef, 2014), and to a lesser extent on proactive resource provisioning (Weinman, 2012; Mazhelis and Tyrväinen, 2012). Likewise, in the literature on concurrent sourcing, multiple factors have been found to affect the optimal mix, including resource co-specialization, supplier selection as well as the cost and benefits of producing in-house resources and buying from external parties (Sako et al., 2013; Puranam et al., 2013), with volume uncertainty found among the factors that warrant additional studies (Sako et al., 2013).

One of the parameters shaping the optimal mix of sourcing is the *reassessment interval* (also referred to as acquisition cycle time), which can be defined as the time period between successive time points when the organization reassesses its sourcing needs and acquires additional resources for in-house use (Laatikainen et al., 2014). For instance, if the company acquires additional private resources once a year, then the length of the reassessment interval is one year. The demand reassessment interval affects the degree of volume variation, because both the expected change of the demand and the difficulty of estimating it increase with the length of the interval. Therefore, it can be hypothesized that the demand reassessment interval, through its effect on volume variation, impacts on how much to produce internally versus how much to procure from external sources, and determines the volume of cost savings that are attainable by hybrid cloud storage.

The objective of this paper is to increase our understanding of the economic effect that the reassessment interval and volume variation have on the cost of hybrid cloud infrastructure. In particular, the paper studies hybrid cloud storage as a subset of hybrid cloud infrastructure, the popularity of which has increased dramatically in recent years and which is predicted to increase even further (TwinStrata, 2013; McClure, 2014).

The practical issue addressed in this paper is that of determining how much storage to provision from in-house resources and how much to procure on-demand from the public cloud resources. Whereas numerous factors, including the need to deliver the required level of service and comply with applicable legislation, have an effect on the cloud sourcing decisions (Fadel and Fayoumi, 2013; Andrikopoulos et al., 2013), this paper focuses on the cost-efficiency of the resulting mix of resources, which is a key factor affecting these decisions (Agarwala et al., 2011) and, thus, is a crucial issue faced by cloud infrastructure practitioners (Weinman, 2012; Altmann and Kashef, 2014).

In earlier works on hybrid cloud computing, it has been shown that the cost-optimal time of using public cloud computing resources is the inverse of the premium charged by the public cloud provider (Weinman, 2012; Mazhelis and Tyrväinen, 2011; 2012). Once the future workload is known or estimated, the cost-optimal time of using the public cloud can be found, and the cost-optimal portion of the workload to serve in-house can be estimated. For this, the fluctuating demand curve is re-arranged to be a monotonically non-decreasing function, and the maximum workload at the time when the in-house resources only are used indicates the volume of resources to be provisioned in-house (Mazhelis and Tyrväinen, 2012). In the case of storage, fluctuations are rare; instead, the demand for storage is usually a monotonically non-decreasing function (Laatikainen et al., 2014). Nevertheless, within a single period between subsequent sourcing decisions, the same logic of determining the cost-optimal mix of in-house and external storage resources can be used, thus suggesting that the use of the hybrid approach yields cost benefits in the context of cloud storage resources as well.

The research question addressed in this paper can be formulated as follows:

How does the demand reassessment interval, through its effect on the volume variation experienced by the organization, impact the cost-efficient mix of internal and external sourcing in hybrid cloud storage?

The following two hypotheses are formulated:

(i) Shortening the reassessment interval leads to smaller unutilized excess capacity, thereby reducing the inefficiencies of scale.
(ii) Shortening the reassessment interval may reduce the demand estimation error, thereby further reducing inefficiencies of scale by minimizing the departure from cost-optimal sourcing.

The paper subscribes to the design science research (DSR) paradigm (Hevner et al., 2004; Peffers et al., 2007; Gregor and Hevner, 2013) wherein an innovative artifact – in the form of a conceptual-analytical model – is constructed and evaluated, in order to increase our understanding of concurrent sourcing in the IS domain and to address the practical issue of determining the cost-optimal mix of internal and external storage resources. This model is systematically evaluated in the paper, being (i) analytically investigated to demonstrate the inherent regularities of the model, and then (ii) empirically evaluated in simulation studies reflecting real-life scenarios.

The contribution of this paper is two-fold. First, by studying the concurrent sourcing phenomenon in the context of cloud infrastructure, the specific aspects of the latter, such as non-decreasing demand for storage and relatively high utility premiums, can be taken into account, thus deepening our understanding of concurrent sourcing in the IS domain. Second, this paper contributes to the theoretical foundations of IS management by allowing managers to compare the savings attainable through shortening the resource acquisition cycle with the cost of acquiring the organizational capability needed for shortening the cycle. In other words, the paper helps in applying agile principles to IS management by offering a tool for comparing the cost savings gained through the flexibility of concurrent sourcing with the costs of cloud transformation for the purpose of enabling such sourcing.

Furthermore, the results of the study can be added to the general body of knowledge of concurrent sourcing, thereby helping to resolve the contradictions present in the contemporary concurrent sourcing literature. Studying the role of volume uncertainty analytically, as a central concept of concurrent sourcing literature, provides previously unknown insights into the role of volume uncertainty in an organization's choice of different sourcing forms as well as the optimal allocation between buy and make, and helps in achieving one of the goals of concurrent sourcing – maximizing the volume of cost saving, which is particularly crucial during economic downturns.

The paper is organized as follows. In the next section, related research in the field of hybrid cloud storage is surveyed. Section 3 introduces the analytical model of hybrid cloud storage costs and investigates the regularities inherited in the model. This model is further empirically evaluated in Section 4 using simulation studies reflecting real-life scenarios. In Section 5, the theoretical and practical implications of the constructed model are discussed, and the directions for further research are outlined. Finally, conclusions are presented in Section 6.

2. Related work

This section provides an overview of related work in the field of cloud storage in general (Section 2.1), and hybrid cloud storage in particular (Section 2.2). In Section 2.3, hybrid cloud storage is discussed as an instantiation of the concurrent sourcing phenomenon. The section ends with a summary of the applicable cost factors, and it indicates the gaps in research where further study is needed (Section 2.4).

2.1. Cloud storage

The popularity of using cloud storage services has increased dramatically in recent years, and it is predicted to increase further, partially due to the fact that the growth of storage capacity demand outpaces the capacity growth attainable in-house. For example, 84% of survey respondents attending the Cloud Computing Expo in New York in June 2013 indicated that they were planning to use or were already using cloud storage (TwinStrata, 2013).

Generally, data stored in the cloud may be characterized by large capacity, varying data access patterns, soft performance requirements, online access from different geographical locations, and low management overhead (Agarwala et al., 2011). When the application is data intensive, the most important requirements are data durability, availability, access performance, usability, and support for security and privacy (Palankar et al., 2008). However, besides rich functionality, low cost is among the most essential requirements (Agarwala et al., 2011).

Organizations may follow different approaches to maximize the cost-efficiency of cloud storage. First of all, they may store only the provenance for the data and regenerate the rest when needed (Borthakur, 2007; Adams et al., 2009). In this case, in addition to deciding upon trading storage for computing requirements based on a cost-benefit analysis, the organizations also have to consider whether the stored data can be feasibly computed, whether the exact result may be replaced with an acceptable approximation, and whether the legal and security requirements are met (Adams et al., 2009). Different strategies have been proposed in Yuan et al. (2010a); 2010b); 2011) to find the best trade-off between storage and computational costs by storing the appropriate intermediate data in cloud storage. The need for incorporating the provenance services into cloud storage offerings is also emphasized by Muniswamy-Reddy and Seltzer (2010), who analyze several alternative implementations that collect provenance data and use the cloud as a back end.

Another approach to decreasing the costs of cloud data storage is to use data transformation, such as compression, deduplication, and transcoding (Agarwala et al., 2011). Compression algorithms offer different trade-offs between the decrease in storage volume and the increase in resource consumption (memory, CPU cycles) as well as the additional delays in restore operations (Mao et al., 2014; Agarwala et al., 2011). Data deduplication is a type of data compression that is often used in cloud backup and archiving systems as well as in primary storage for virtual machine servers to reduce the amount of storage space consumed (Mao et al., 2014). Depending on the redundancy requirements, by storing only one single instance of each unique data chunk, storage needs may be reduced by as much as 80% for VM servers, and backup and archiving applications also benefit significantly from data deduplication (Mao et al., 2014; Clements et al., 2009). Current storage systems use erasure codes, such as Reed-Solomon codes, for storing infrequently assessed data (the so-called cold data) to ensure its redundancy (André et al., 2014; Jiekak et al., 2013), whereas frequently accessed data (the so-called hot data) is replicated in multiple disk massives to provide high availability from non-reliable devices (André et al., 2014; Jiekak et al., 2013).

To achieve cost reduction of cloud data centers, data replication mechanisms may be used in conjunction with different energy saving strategies Long et al. (2014). Different algorithms exist to spin down the data nodes from the high energy consumption mode into a lower standby mode when they are inactive

(Zhu et al., 2005; Long et al., 2014; Xie, 2008; Weddle et al., 2007). Storage cost may also be reduced by employing efficient audit services to ensure data integrity (Zhu et al., 2012).

The research work outlined above primarily addresses issues pertaining to public cloud storage, whereas relatively little attention has been devoted to hybrid cloud storage and its related costs. In the next subsection, the literature on hybrid cloud infrastructure, with a special focus on hybrid cloud storage, is surveyed.

2.2. Hybrid cloud storage

Hybrid cloud computing infrastructure is a composition of private and public clouds where in-house and public resources are concurrently used in order to enable data and application portability (Armbrust et al., 2010; Mell and Grance, 2011). In a recent survey, over 70% of enterprises have chosen to adopt hybrid cloud infrastructure (RightScale, 2014). In light of these results showing its importance, it is not surprising the hybrid cloud has been researched widely.

Research has been devoted to the two core technical enablers of hybrid cloud computing – virtualization and multi-tenancy – that allow cloud resources to be pooled together to serve multiple clients (Smith and Nair, 2005; Bittencourt and Madeira, 2011; Kabbedijk et al., 2015; Cai et al., 2010). In addition, much research work has focused on partitioning, that is, deciding which applications, application components, or computing jobs must be kept local, and which ones must be migrated to the public cloud (Fan et al., 2011; Huang and Shen, 2015; Tak et al., 2013). In a hybrid environment, different policies might determine if the application or the workload is assigned to the private or public cloud, such as application-specific functionalities and requirements (Khajeh-Hosseini et al., 2011; Fan et al., 2011; Wang et al., 2012; Hajjat et al., 2010; Juan-Verdejo and Baars, 2013), economic, security and privacy implications (Silva et al., 2013), data sensitivity, and high performance requirements (Zhang et al., 2014). Alternatively, the placement may be decided on the fly depending on the current load of the system (Mazhelis, 2012). In this case, organizations can use cloud bursting, the process by which excess load is offloaded to public cloud infrastructure if the workload exceeds a specific threshold.

One of the key research questions in cloud bursting is to determine the workload or portion of a workload that should be offloaded (Fadel and Fayoumi, 2013). It has been shown that the cost-optimal time of using the public cloud is the inverse of the premium charged by the public cloud provider (Weinman, 2012; Mazhelis and Tyrväinen, 2011; 2012). Furthermore, Mazhelis and Tyrväinen (2011); 2012) have shown that data communication overheads as well as the volume discounts set by the public cloud provider affect the cost-optimal time of using the public cloud. Knowing the future workload and the cost-optimal time of using the public cloud, the cost-optimal portion of the workload to serve in-house can be estimated.

Instead of looking at processes that determine a suitable distribution of workloads in advance, a related stream of research concentrates on automatic resource provisioning. This is when application requests are mapped to the distributed physical resources on the fly and the execution of the applications are scheduled on the fly (e.g., Calheiros et al., 2011; Andrikopoulos et al., 2013; Sun et al., 2015; Cerviño et al., 2013; Trummer et al., 2010).

The studies on hybrid cloud storage, in particular, may be exemplified with the model by Lima et al. (2014), which explicitly takes into account latency, uptime, free size, and cost when determining the most appropriate placement of data in a hybrid cloud. In Abu-Libdeh et al. (2010), a system is provided for stripping the data across multiple providers in order to reduce the cost of vendor lock-in and facilitate switching providers, as well as to better tolerate provider outages or failures. In their work, Villari et al. present a solution for distributing the data across many cloud storage providers while enforcing long-term availability, data confidentiality, and data redundancy (Villari et al., 2013; 2014; Celesti et al., 2016). Furthermore, the use of data filtering to reduce intercloud data transmission overheads has been explored by Han et al. (2013), with the aim of improving the cost-efficiency of applications where the performance of a hybrid cloud may not be sufficient due to low bandwidth and high latency of data communications between private and public clouds. However, to a large extent, the available research either infuses the storage-related issues as part of comprehensive hybrid cloud considerations (e.g., Malawski et al., 2013) or focuses on security as a primary design objective (e.g., Dobre et al., 2014).

The relative scarcity of the research on hybrid cloud storage can be explained by the fact that cloud storage services initially relied solely on public storage infrastructure. Meanwhile, as the results of a recent survey by Enterprise Strategy Group indicate, the majority of IT professionals participating in the survey are extremely (69%) or somewhat (28%) interested in hybrid cloud storage (McClure, 2014). This suggests that hybrid cloud storage will likely become the subject of increasing interest to the research community in the near future.

2.3. Hybrid cloud storage as a form of concurrent sourcing

Hybrid cloud infrastructure in general and hybrid cloud storage in particular can easily be seen as a form of concurrent sourcing. Concurrent sourcing refers to the simultaneous use of market contracting and vertical integration, that is, it means producing as well as buying the same good or service. This phenomenon has gained increasing attention in recent literature on organization and strategic management, where it has been labeled as, for example, tapered integration (Porter, 1980), partial integration (Jacobides and Billinger, 2006), concurrent sourcing (Parmigiani, 2007; Parmigiani and Mitchell, 2009; Heide et al., 2013; Mols, 2010), plural sourcing (Jacobides and Billinger, 2006), and plural governance (Heide, 2003). It has also been studied from the viewpoint of various theories, including transaction cost economics, agency theory, resource-based theory, neoclassical economics, life cycle theory, resource and capability view, theories of multi-profit center firms, marketing channels, options theory and knowledge-based theory (Mols et al., 2012; Mols, 2010). For consistency, the term concurrent sourcing will be used throughout this paper.

The theoretical explanations of concurrent sourcing and the available empirical results shed some light on why some organizations use hybrid cloud solutions. They suggest, for instance, that volume uncertainty coupled with the high cost of excess capacity, along with factors such as performance ambiguity, technological volatility, and information asymmetry, likely contribute to the popularity of concurrently using private and public clouds. Furthermore, the open issues that require further studies in concurrent sourcing literature – including the role of volume uncertainty and variability – are relevant in the context of the hybrid cloud as well and warrant further investigation.

When seen through the lens of hybrid cloud research, the concurrent sourcing literature has two limitations. First, the findings in the extant literature on concurrent sourcing may not be sufficient for explaining the concurrent use of private and public cloud infrastructure. This is due to the fact that the concurrent sourcing research may fail to take into account some key aspects of the hybrid cloud, such as the possibility to fulfill QoS or legal requirements (e.g., regarding data availability and confidentiality) with private cloud resources while benefiting from inexpensive external resources to execute the components with less stringent requirements (Juan-Verdejo and Baars, 2013).

Table 1
Metrics used in cost-based analysis of cloud deployment alternatives.

Net present value of money	Tak et al. (2013); Brumec and Vrček (2013); Walker et al. (2010); Mastroeni and Naldi (2011); Mazhelis (2012)
Total cost of ownership	Klems et al. (2009); Koomey et al. (2007); Martens et al. (2012); Han (2011); Walterbusch et al. (2013); Mazhelis et al. (2012b); Bibi et al. (2012); Brumec and Vrček (2013); Mazhelis et al. (2012b)
Value-at-risk	Mastroeni and Naldi (2011)
Return on investment (ROI)	Beaty et al. (2011); Misra and Mondal (2011)

Second, it has to be noted that, in the concurrent sourcing literature, the optimal mix of in-house and external resources has been explained in terms of market conditions and firm strategy. However, the hybrid cloud literature also contains a growing body of knowledge that focuses on other factors affecting optimal dynamic allocation of resources and which takes into account various requirements and constraints. These factors can be useful in explaining concurrent sourcing in contexts other than the hybrid cloud, meaning that the hybrid cloud literature can contribute to a deeper general understanding of the concurrent sourcing phenomenon.

Overall, the concurrent sourcing literature offers limited analytical and empirical insight into the role of volume uncertainty in concurrent sourcing. Therefore, there is a need for analytical inquiry focusing on this subject as well as for gathering empirical evidence to validate the findings. Hybrid cloud storage represents a contemporary context for such an inquiry, the specifics of which (e.g., specific forms of demand curves, quality-of-service requirements, or data sensitivity concerns) will provide new insight into concurrent sourcing.

2.4. Cost factors in hybrid cloud infrastructure

From the perspective of neoclassical economics, the use of hybrid cloud infrastructure as a form of concurrent sourcing allows an organization to hedge against the risks of underutilized excess capacity, and therefore minimize the infrastructure-related costs. Different cost-based metrics are available to the decision-makers who are deciding upon the possible adoption of a cloud solution. A summary of these metrics is provided in Table 1 below, along with references to the research where these metrics have been developed or applied.

The research on the cost-efficiency of (hybrid) cloud infrastructure suggests that the cost-efficiency of the hybrid cloud is determined by a variety of cost factors that have a compound non-linear effect on the overall costs. These costs factors, considered in the extant literature on cloud computing, can be grouped into several categories (Table A.3 in the appendix lists the references to the publications where these cost factors have been studied):

1. *Cost factors related to in-house resources:* the cost of acquiring, provisioning and maintaining an in-house data center during its entire lifecycle, including hardware and server costs, software license fees, electricity and labor costs, business premises, as well as the adjacent cost factors related to the strategy and the practices of the organization (e.g., acquisition and forecasting intervals, the degree of data center utilization).
2. *Cost factors related to public resources:* the cost of computations, storage, data communications, load balancing, and other adjacent cost factors, such as the pricing models of cloud providers, charging period, volume discount, market and technological trends.
3. *Cost factors reflecting the interaction between the private and public cloud and/or the use of a private and public cloud concurrently:* partitioning and allocation costs, data communication intensity between the private and public cloud, the threshold for workload re-allocation between in-house and external subsystems.
4. *Cost factors related to the organizational, environmental, or system context:* the usage pattern of the system or the service, the demand growth rate, variability and uncertainty, the type of applications and their requirements, system architecture, size of the organization.
5. *Other cost factors:* costs related to the decision-making on possible cloud adoption and the selection of a cloud provider; costs of deployment, integration, migration and configuration; support and maintenance cost; training costs; potential losses due to cloud adoption.

Even though a plethora of cost models with various granularities of cost factors have been studied, the effect of the demand reassessment interval and the volume variation on the costs of hybrid cloud storage has not been considered yet in the literature. The work closest to ours is that by Laatikainen et al. (2014), where the role of the acquisition interval in the cost-efficiency of the private versus public cloud has been analyzed. Although the acquisition interval has been studied in the context of selecting between private and public storage, to the best knowledge of the authors no publicly available research focuses on the role of the reassessment interval and volume variation in the cost efficiency of hybrid cloud storage. Therefore, below, a hybrid storage cost model is introduced where the compound effect of the reassessment interval and volume variation is taken into account.

3. Modeling the cost of hybrid cloud storage

Let us consider the cost of a hybrid cloud storage system, where a private and a public cloud infrastructure together serve an organization's storage demand. The system can be decomposed into two subsystems: the private subsystem provided by the in-house resources, and the public subsystem provided by the public cloud.

3.1. Assumptions

Before introducing the analytical model for hybrid storage costs, several assumptions have to be made. The core assumptions are listed below, while the other assumptions are introduced as appropriate later in the paper.

1. First, we assume that the storage demand is a non-decreasing function in time. Indeed, as opposed to the demand for computing resources that often exhibits seasonal and other periodic fluctuations, the demand for storage tends to accumulate over time, due to the fact that newly created digital content only partially replaces the content already stored (Laatikainen et al., 2014). As a result, the digital universe as a whole grows 40% a year, according to a recent study by IDC.[1]
2. Second, we assume that the organization aims to achieve cost savings by allocating the cost-optimal amount of resources to the private subsystem. For this, the organization is assumed to periodically reassess its future storage needs and proactively acquire additional storage capacity. To minimize the storage-related costs, the organization may intentionally decide to acquire the storage resources to fulfill less than 100% of its future storage needs.

[1] http://www.emc.com/leadership/digital-universe/2014iview/executive-summary.htm

3. Third, for the sake of simplifying the analysis, we assume that each unit of data is atomic in the sense that (i) it bears the same level of criticality,[2] and (ii) it is stored on either the public or private portion of the system. In other words, it is assumed that no unit of data is distributed between private and public subsystems or replicated in another cloud infrastructure. As a result, the interaction between the private and public subsystems can be assumed to be negligible.
4. Finally, the organization is assumed to allocate the storage on a private-first–public-second basis. Specifically, whenever a need to allocate storage emerges, the required storage space is allocated from the pool of the organization's in-house resources, provided that unused storage is still available in-house. However, when the demand for storage exceeds the capacities available in-house, the storage space to accommodate the excess demand is allocated from the public cloud.

Using these assumptions, we can consider the cost components comprising the hybrid storage cost model. As overviewed in the previous section, different cost components are relevant for the private and the public subsystems. For the private subsystem, the relevant cost constituents include the costs of hardware and software acquisition, integration, configuration and upgrading, as well as the recurring costs of renting floor space, power, bandwidth, and the cost of administration and maintenance. The overall cost of the private storage subsystem is thus a function of the demand, as well as of its growth pattern and its predictability, the time interval between storage acquisitions, and the pricing of the needed equipment, software, and personnel, among other costs.

On the other hand, for public cloud storage, the cost components include usage-dependent costs such as, in the case of Amazon S3, the costs of storage capacity, data transfer, and input/output requests. Depending on the charging policy of the storage service provider, the cost of the storage may be determined by the maximum or average volume of storage occupied during the charging period. For instance, Amazon Web Services (AWS) charges its customers based on the maximum storage capacity used in 12-hour intervals.[3]

In the case of hybrid cloud storage, the process of acquiring, provisioning and paying for the necessary storage resources differs between the private and public subsystems. On the one hand, the *private* subsystem's resources cannot be added to instantly when the need arises, because there is a definite amount of time for the resources to be provisioned upon request–this time period is referred to as the provisioning interval (Weinman, 2011c; 2012). Therefore, the organization has to manage the private subsystem proactively. It must periodically estimate its future demand and acquire and deploy the additional resources for the in-house storage infrastructure in advance. The interval between the subsequent resource acquisitions based on the future demand estimates is referred to here as the *reassessment interval*. The cost of the private storage subsystem is incurred at the beginning of each reassessment interval and so it depends on the maximum storage capacity and estimation accuracy rather than on the actual use of storage resources.

On the other hand, the *public* subsystem's resources can be provisioned with a negligible delay. When the demand for storage exceeds the available private cloud capacity, the organization can acquire additional resources from the public cloud provider and then deploy the excess data to the public subsystem. As opposed to the private subsystem, the organization pays for the public subsystem's resources only when they are used and only for the volume of storage in the public subsystem that is actually used.

[2] Here, depending on the nature of the organization's business, the criticality may encompass confidentiality, reliability, availability, and other considerations.

[3] http://aws-portal.amazon.com/gp/aws/developer/common/amz-storage-usage-type-help.html

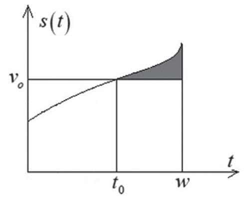


Fig. 1. Hybrid cloud costs without refinement of reassessment interval.

As stated above, in this paper we assume that the organization aims to achieve cost savings by allocating the cost-optimal amount of resources to the private subsystem. This cost-optimal allocation depends on the forecasted or known storage demand, the utility premium of the cloud provider, and the length of the reassessment interval, which are the main subjects of the analysis in this section. The total cost of hybrid cloud storage is also affected by many additional factors, such as the cost of adopting a hybrid infrastructure, data transfer costs, pricing trends, volume discounts, cost savings achievable by storing only the provenance data and regenerating the rest when needed, or cost savings due to data transformations (see Section 2), among other factors. Combined, these factors are likely to have a complex, non-linear effect on the overall costs, making them difficult to analyze (Mazhelis and Tyrväinen, 2012). In order to simplify the analysis, in this paper it is assumed that these additional factors either have a minor effect or affect similarly the costs of both the private and the public storage subsystems, and hence are left outside of the scope of the analysis.

The remainder of the section is organized as follows. First, in Section 3.2, we introduce a hybrid cloud storage cost model that captures the role of the reassessment interval in the hybrid cloud costs under the assumption that the growth of the storage demand is well-known or that there is no estimation error. After that, in Section 3.3, we relax this assumption and include the volume uncertainty in the model in order to assess the impact of the reassessment interval on the hybrid cloud storage costs when the demand is imperfectly estimated.

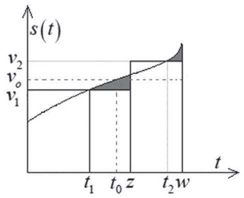
3.2. General hybrid storage cost model

Let us define the demand function $s(t) \mapsto \mathbb{R}$ that maps from time to quantity of needed resources. As stated above, due to the increasingly growing nature of storage needs, this function is assumed to be positive and increasing. Note that the form of the demand function $s(t)$ reflects the former aspect of the volume variation: variability, meaning the non-stationary nature of the demand.

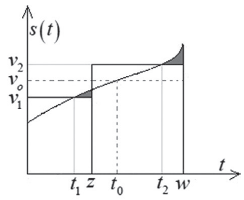
Let us consider the total cost of a hybrid storage solution during the reassessment interval of length w as shown in Fig. 1. Since, in a hybrid solution, the private and public subsystems are used in combination, the total hybrid cloud storage costs C_{H1} are the sum of the private costs C_o and public costs C_p.

First, let us evaluate the costs of owning the private storage subsystem C_o during the reassessment interval of length w. As described above, at the beginning of each reassessment interval, the company estimates the amount of resources needed during the following reassessment interval and acquires the necessary storage accordingly. Thus, having denoted the total cost of owning a unit of private storage capacity v over time t as $p_o(v)$, the cost of owning in-house capacity C_o can be estimated as

$$C_o = v_0\, p_o(v_0)\, w, \quad (1)$$



(a) $z > t_0$



(b) $z < t_0$

Fig. 2. Hybrid cloud costs with a refinement of the reassessment interval. A cost-optimal allocation of resources to the private cloud is assumed.

where v_0 is the maximum private storage capacity to be used within the next reassessment interval. In case the actual demand $s(t)$ exceeds v_0, the difference $s(t) - v_0$ will be served by using public cloud resources.

The cost of the public cloud storage subsystem C_p can be evaluated by calculating the costs of public storage over the period when the public cloud is used. Let $p_p(s(t))$ denote the price of a unit of storage per unit of time set by the public storage provider. We will assume for simplicity that the demand for the public resources is served immediately. Thus, the cost of public storage C_p accumulated over the reassessment interval of length w is

$$C_p = \int_{t_0}^{w} p_p(s(t))s(t)dt - p_p(v_0)\, v_0\, (w - t_0), \tag{2}$$

where t_0 is the time point when $s(t_0) = v_0$ and, therefore, $w - t_0$ is the length of the time interval during which the public subsystem is used.

We shall assume that the price of a unit of public storage capacity is greater than the cost of a unit of private storage. This is justified by the fact that the public storage provider charges a premium for the organization's flexibility in rapidly provisioning and deprovisioning the resources (Weinman, 2011a). As a result, some organizations found it significantly less expensive to host their own storage facilities than to use the storage capacity of Amazon, with the difference up to the factor of 26 (Nufire, 2011). Thus, it can be written that $p_p(s(t)) = u(s(t))\, p_o(s(t))$, where $u(s(t)) > 1$ is the utility premium ratio, or, in short, the utility premium of the public storage vendor. To simplify the further analysis, the utility premium shall incorporate (i) the cost of transferring the excess data to and from the public subsystem and (ii) the cost of transferring the cumulated public storage capacity to the private subsystem once the private capacity is increased.

In order to make the analysis tractable, we further assume that the prices are not subject to volume discounts. Therefore, for brevity, we shall refer to $p_p(s(t))$ and $p_o(s(t))$ as p_p and p_o, respectively, and thus, Eq. (2) can be rewritten as follows:

$$C_p = u\, p_o \int_{t_0}^{w} s(t)dt - u\, p_o\, v_0\, (w - t_0). \tag{3}$$

Thus, the total hybrid cloud storage costs C_{H1} are

$$C_{H1} = p_o\, v_0\, w + u\, p_o \left(\int_{t_0}^{w} s(t)dt - v_0\, (w - t_0) \right). \tag{4}$$

Let us now consider the cost-impact of shortening the reassessment interval. Specifically, let us consider the case when the reassessment interval is refined, that is, when it is divided into two adjacent reassessment intervals $P1$ and $P2$ of the lengths z and $w - z$, respectively (see Fig. 2). Let us mark the maximum private storage over the period $P1$ with v_1, and over the period $P2$ with v_2.

Using the same notations as introduced above, the total hybrid cloud storage costs in the period $P1$ can be expressed as

$$C_{HP1} = p_o\, v_1\, z + u\, p_o \left(\int_{t_1}^{z} s(t)dt - v_1\, (z - t_1) \right), \tag{5}$$

where $s(t_1) = v_1$ and $z - t_1$ is the length of the time period where the public cloud is used.

Similarly, the total hybrid cloud storage costs for the period $P2$ are

$$C_{HP2} = p_o\, v_2\, (w - z) + u\, p_o \left(\int_{t_2}^{w} s(t)dt - v_2\, (w - t_2) \right),$$

where $s(t_2) = v_2$ and $w - t_2$ is the length of the time period when the public cloud is used.

We will mark the total hybrid costs with C_{H2} for the case when the reassessment interval is refined. C_{H2} can then be calculated as the sum of the costs for reassessment intervals $P1$ and $P2$:

$$C_{H2} = C_{HP1} + C_{HP2}. \tag{6}$$

Let us define the cost difference function $f = C_{H1} - C_{H2}$. If $f > 0$, then refining the reassessment interval is beneficial costwise. Otherwise, if $f < 0$, the hybrid costs are increasing when the reassessment interval is divided into two smaller intervals.

The cost difference thus can be written as

$$\begin{aligned} f &= C_{H1} - C_{H2} = \\ &= p_o\, v_0\, w - u\, p_o\, v_0\, (w - t_0) - p_o\, v_1\, z + u\, p_0\, v_1\, (z - t_1) \\ &\quad - p_o\, v_2\, (w - z) + u\, p_0\, v_2\, (w - t_2) \\ &\quad + u\, p_o \left(\int_{t_0}^{w} s(t)dt - \int_{t_1}^{z} s(t)dt - \int_{t_2}^{w} s(t)dt \right). \end{aligned} \tag{7}$$

It can be seen from the equation above that the sign of f depends on the utility premium charged by the public cloud provider, on the length of time period when the public cloud is used, on the demand function, and on the percentage of the actual demand that is allocated to the private cloud.

In order to simplify the analysis, we take into account the above stated assumption that, at the beginning of each reassessment interval, the organization acquires storage capacity to the private cloud so as to minimize the overall hybrid storage costs. According to Mazhelis and Tyrväinen (2012) and Weinman (2012), the cost-optimal portion of time to use the public cloud is the inverse of the premium charged by the cloud provider (see Corollary 1 in Mazhelis and Tyrväinen (2012)). It follows from this assumption that

$$t_0 = \frac{u-1}{u} w, \tag{8}$$

$$t_1 = \frac{u-1}{u} z, \tag{9}$$

$$t_2 = z + \frac{u-1}{u} (w - z). \tag{10}$$

As a result, it can be shown that the cost difference function simplifies to

$$f = u\, p_o \left(\int_{\frac{u-1}{u} w}^{w} s(t)dt - \int_{\frac{u-1}{u} z}^{z} s(t)dt - \int_{z + \frac{u-1}{u} (w-z)}^{w} s(t)dt \right). \tag{11}$$

Proposition 3.1. *Assuming the allocation of cost-optimal amount of storage capacity to private cloud and no reassessment costs, re-evaluating the storage needs more often is always beneficial costwise, that is, $f > 0$.*

Proof. The proof of the proposition is provided in Appendix B.1. □

Let us further consider the cost-efficient division of the reassessment interval, by analyzing which division point z allows the cost difference, as reflected in f, to be maximized.

Lemma 3.1. *In the interval* $(0, w)$, $f(z)$ *has only one extremum point where* $\frac{\partial f}{\partial z} = 0$, *and this extremum corresponds to the maximum of* $f(z)$ *in the region* $(0, w)$.

Proof. The proof of the lemma is provided in Appendix B.2. □

Note that the value of z_{max} depends on the form of the demand function. Let us illustrate the cost-efficient division of the reassessment interval in case of a linear demand function that can be defined as

$$s(t) = a\,t + b, \tag{12}$$

where $a > 0$ (assuming that the demand is monotonically increasing) and $b > 0$ (assuming that the demand is positive at the beginning of the storage period) are real numbers. In this case, the cost difference function f is simplified to

$$f = p_o \frac{a\,z\,(u-1)\,(w-z)}{u}. \tag{13}$$

Lemma 3.2. *In the case of a linearly growing demand function, the greatest cost-savings can be achieved when* $z = w/2$.

Proof. The proof of the lemma is provided in Appendix B.3. □

However, in the case of an exponentially growing demand function, the largest cost difference is attainable by splitting the reassessment interval into two, with the latter subinterval being shorter.

Lemma 3.3. *In the case of an exponentially growing demand function, the greatest cost-savings can be achieved when* $z > w/2$.

Proof. The proof of the lemma is provided in Appendix B.4. □

Let us investigate the impact of the utility premium on the cost difference function (13). For this, consider the first derivative of the cost difference function with respect to the utility premium, which can be written in the following form:

$$\begin{aligned}
\frac{\partial f}{\partial u} &= p_o\,(F(t_2) - F(t_0) + F(t_1) - F(z)) \\
&\quad + u\,p_o \left(\frac{\partial}{\partial u}F(t_2) - \frac{\partial}{\partial u}F(t_0) + \frac{\partial}{\partial u}F(t_0) \right) \\
&= p_o\,(F(t_2) - F(t_0) + F(t_1) - F(z)) \\
&\quad + u\,p_o \left(\frac{\partial F(t_2)}{\partial t_2}\frac{\partial t_2}{\partial u} - \frac{\partial F(t_0)}{\partial t_0}\frac{\partial t_0}{\partial u} + \frac{\partial F(t_1)}{\partial t_1}\frac{\partial t_1}{\partial u} \right) \\
&= p_o\,(F(t_2) - F(t_0) + F(t_1) - F(z)) \\
&\quad + u\,p_o \left(s(t_2)\,\frac{w-z}{u^2} - s(t_0)\,\frac{w}{u^2} + s(t_1)\,\frac{z}{u^2} \right).
\end{aligned} \tag{14}$$

Referring to Eq. (B.1) it can be seen that the first term in the expression above is positive:

$$p_o\,(F(t_2) - F(t_0) + F(t_1) - F(z)) > 0.$$

Furthermore, the sign of the term

$$u\,p_o \left(s(t_2)\,\frac{w-z}{u^2} - s(t_0)\,\frac{w}{u^2} + s(t_1)\,\frac{z}{u^2} \right) \tag{15}$$

depends on the demand curve $s(t)$ or, more precisely, on how great $s(t_0)\,\frac{w}{u^2}$ is in relation to $s(t_2)\,\frac{w-z}{u^2} + s(t_1)\,\frac{z}{u^2}$.

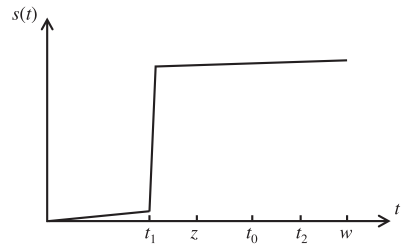


Fig. 3. Special case of the demand curve that grows very slowly before t_1 and after t_0 but very rapidly in the range $(t_1, t_1 + |\delta|), \delta \to 0$.

Let us now investigate the special case when the demand curve grows very slowly before t_1 and after t_0, but very rapidly in the range $(t_1, t_1 + |\delta|), \delta \to 0$ (as shown in Fig. 3). In this case, $s(t_2) \approx s(t_0)$ and $s(t_1) \to 0$.

Therefore,

$$p_o\,(F(t_2) - F(t_0) + F(t_1) - F(z)) = p_o \left(\int_{t_0}^{t_2} s(t)dt - \int_{t_1}^{z} s(t)dt \right) \to 0,$$

whereas

$$u\,p_o \left(s(t_2)\,\frac{w-z}{u^2} - s(t_0)\,\frac{w}{u^2} + s(t_1)\,\frac{z}{u^2} \right) \approx -\frac{p_o}{u} s_o z.$$

As a result, it follows that

$$\frac{\partial f}{\partial u} \approx -\frac{p_o}{u} s_o z < 0.$$

However, for more conventional demand growth functions, the value of the derivative is likely to be positive, and therefore the observation holds that the greater the utility premium, the greater the cost savings due to the refinement of the reassessment interval. Let us illustrate it with an example of linear demand growth.

Lemma 3.4. *In the case of linearly growing demand, the greater the utility premium, the greater the cost savings due to the refinement of the reassessment interval.*

Proof. The proof of the lemma is provided in Appendix B.5. □

Let us introduce the cost of reassessment c_r, that is, a cost associated with each re-assessment event. The reassessment cost includes, among others, the cost of demand estimation for the next reassessment interval and the procurement and deployment of the additional storage resources. Being dependent on the internal practices of the organization, the reassessment cost is difficult to estimate. However, for the sake of simplicity, we will assume that the reassessment cost is the same for each reassessment interval within the same organization and is independent of the volume of the storage, either available or to be purchased.

Let us calculate the total hybrid cost C_{H1} (Eq. (4)) when the reassessment cost is taken into account:

$$C_{H1} = c_r + p_o\,v_0\,w + u\,p_o\,(\int_{t_0}^{w} s(t)dt - v_0\,(w - t_0)). \tag{16}$$

If the reassessment interval is refined, that is, split into two intervals, the reassessment cost is incurred twice:

$$C_{H2} = 2\,c_r + C_{HP1} + C_{HP2} \tag{17}$$

In this case, the cost difference function f is the following:

$$\begin{aligned}
f = C_{H1} - C_{H2} &= -c_r \\
&\quad + u\,p_o \left(\int_{\frac{u-1}{u}w}^{w} s(t)dt - \int_{\frac{u-1}{u}z}^{z} s(t)dt - \int_{z+\frac{u-1}{u}(w-z)}^{w} s(t)dt \right).
\end{aligned} \tag{18}$$

Let us refer to Proposition 3.1 and define the *cost benefits due to refinement of the reassessment interval* as the following term from Eq. (11):

$$u\,p_o\left(\int_{\frac{u-1}{u}w}^{w} s(t)dt - \int_{\frac{u-1}{u}z}^{z} s(t)dt - \int_{z+\frac{u-1}{u}(w-z)}^{w} s(t)dt\right).$$

Lemma 3.5. *Assuming the allocation of the cost-optimal amount of storage capacity to the private cloud and non-zero reassessment cost, re-evaluating the storage needs more often is beneficial costwise if the cost savings due to reassessment are higher than the cost of reassessment.*

Proof. The proof of the lemma is provided in Appendix B.6. □

Let us now investigate how refining the reassessment interval *recursively* affects the overall costs. Indeed, by reducing the length of the reassessment interval recursively, cost savings can be achieved in line with Proposition 3.1. However, in line with Lemma 3.5, the reassessment cost associated with each reassessment event reduces the cost savings. Thus, a stopping criteria for the recursive reassessment can be defined where the cost of reassessments exceeds the benefits achievable through reassessments. Formally, the stopping criteria can be defined as follows.

Let C_{H1}, C_{H2}, ... , C_{Hn} be the total hybrid costs when the reassessment interval is divided into 1, 2, ..., n intervals. Let $f_2 = C_{H1} - C_{H2}$, $f_3 = C_{H2} - C_{H3}, \ldots, f_n = C_{H(n-1)} - C_{Hn}$ be the corresponding benefits due to reassessment. It can be shown that if $n \to \infty$ then $f_n \to 0$, that is, at some point, $f_n < c_r$, making further refinements economically inferior. Thus, given the constant reassessment cost c_r, the refinements are economically justifiable as long as $f_i > c_r$.

3.3. Cost model taking into account demand forecasting errors

Let us now turn to the more realistic case when the demand function $s(t)$ is not known by the organization, but needs to be estimated instead. The estimated demand curve $\hat{s}(t)$ is likely to diverge from its real value:

$$\hat{s}(t) = s(t)\,(1+\varepsilon), \tag{19}$$

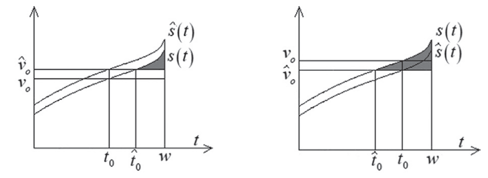
where the estimation error $\varepsilon = \varepsilon(t_y - t_x)$ is a function of the length of the forecasting horizon $t_y - t_x$, the interval between the current time at which the prediction is made t_x and the time for which the prediction is made t_y. Note that this estimation error manifests the latter aspect of volume variation: volume uncertainty, meaning the inaccuracy with which the demand volumes are predicted.

Several assumptions need to be made about the estimation error function. The estimation error may be additive or multiplicative depending on the application. In this study, we assume the estimation error to grow as the amount of estimable storage increases, and hence we use ε to denote a multiplicative error that grows with the storage demand. In addition, the estimation error increases with the forecasting horizon even if the estimable storage demand exhibits little change. Accordingly, the error is assumed to be a non-constant and increasing function of time, although no specific functional form is assumed. Lastly, the demand function is assumed to have negligible or no bias.

The estimation error contaminates the estimates of required storage capacity v:

$$\hat{v}_0 = s(t_0)(1+\varepsilon_0), \text{ where } \varepsilon_0 = \varepsilon(t_0);$$
$$\hat{v}_1 = s(t_1)(1+\varepsilon_1, \text{ where } \varepsilon_1 = \varepsilon(t_1);$$
$$\hat{v}_2 = s(t_2)(1+\varepsilon_2), \text{ where } \varepsilon_2 = \varepsilon(t_2 - z).$$

Importantly, the error in the estimates of v_i also spreads into the "effective" value of t_i, denoted as $\hat{t}_i$, where $i = \{0, 1, 2\}$. For instance, if v_0 is overestimated ($\varepsilon_0 > 0$), it effectively means that



(a) Demand overestimation ($\varepsilon_i > 0, i =$ 1..3, and $\xi_j > 0, j = 1..3$)

(b) Demand underestimation ($\varepsilon_i < 0, i = 1..3$, and $\xi_j < 0, j = 1..3$)

Fig. 4. Dependency between the errors ξ and ε.

the public cloud storage will start to be used later than originally envisioned, $\hat{t}_0 > t_0$. Having denoted the error function impacting t_i as ξ, we can express the "effective" values of t_i as follows:

$$\hat{t}_0 = t_0(1+\xi_0), \text{ where } \xi_0 = \xi(t_0),$$
$$\hat{t}_1 = t_1(1+\xi_1), \text{ where } \xi_1 = \xi(t_1),$$
$$\hat{t}_2 = z + (t_2 - z)\,(1+\xi_2) = z + \frac{u-1}{u}(w-z)\,(1+\xi_2),$$
$$\text{where } \xi_2 = \xi(t_2 - z).$$

Several notes shall be made. First, ξ is also assumed to act as a multiplicative error, in line with ε. Second, the errors ξ and ε are covarying, so if $\varepsilon > 0$, then $\xi > 0$, and vice versa, as demonstrated in Fig. 4 below. Finally, it is important to observe that $\hat{s}(t_i) = s(\hat{t}_i)$.

Taking into account the estimation errors introduced above, for the cost-optimal storage allocation as specified in Eqs. (8–10), the cost difference function f can be rewritten as

$$\begin{aligned} f =\; & p_o s(t_0)(1+\varepsilon_0)w + up_o\left[\int_{\hat{t}_0}^{w} s(t)dt - s(t_0)(1+\varepsilon_0)(w-\hat{t}_0)\right] \\ & - p_o s(t_1)(1+\varepsilon_1)z - up_o\left[\int_{\hat{t}_1}^{z} s(t)dt - s(t_1)(1+\varepsilon_1)(z-\hat{t}_1)\right] \\ & - p_o s(t_2)(1+\varepsilon_2)(w-z) \\ & - up_o\left[\int_{\hat{t}_2}^{w} s(t)dt - s(t_2)(1+\varepsilon_2)(w-\hat{t}_2)\right]. \end{aligned} \tag{20}$$

Having opened $\hat{t}_i$, it can be rewritten in the form

$$\begin{aligned} f =\; & p_o s(t_0)(1+\varepsilon_0)w\xi_0(u-1) + up_o\left[\int_{t_0}^{w} s(t)dt - \int_{t_0}^{\hat{t}_0} s(t)dt\right] \\ & - p_o s(t_1)(1+\varepsilon_1)z\xi_1(u-1) - up_o\left[\int_{t_1}^{z} s(t)dt - \int_{t_1}^{\hat{t}_1} s(t)dt\right] \\ & - p_o s(t_2)(1+\varepsilon_2)(w-z)(u-1)\xi_2 \\ & - up_o\left[\int_{t_2}^{w} s(t)dt - \int_{t_2}^{\hat{t}_2} s(t)dt\right], \end{aligned} \tag{21}$$

or, after regrouping,

$$\begin{aligned} f =\; & f^* + \left(p_o s(t_0)(1+\varepsilon_0)w\xi_0(u-1) - up_o\int_{t_0}^{\hat{t}_0} s(t)dt\right) \\ & - \left(p_o s(t_1)(1+\varepsilon_1)z\xi_1(u-1) - up_o\int_{t_1}^{\hat{t}_1} s(t)dt\right) \\ & - \left(p_o s(t_2)(1+\varepsilon_2)(w-z)\xi_2(u-1) - up_o\int_{t_2}^{\hat{t}_2} s(t)dt\right), \end{aligned} \tag{22}$$

where $f^* = up_o\left[\int_{t_0}^{w} s(t)dt - \int_{t_1}^{z} s(t)dt - \int_{t_2}^{w} s(t)dt\right]$ is the value of the cost difference function in case the estimation of demand is free of estimation error, as specified in Eq. (11).

Based on the equation above, the difference $f - f^*$ can be expressed as

$$\Delta = f - f^* = \left[p_o s(t_0)(1+\varepsilon_0) w \xi_0 (u-1) - u p_o \int_{t_0}^{\hat{t}_0} s(t)dt \right]$$
$$- \left[p_o s(t_1)(1+\varepsilon_1) z \xi_1 (u-1) - u p_o \int_{t_1}^{\hat{t}_1} s(t)dt \right]$$
$$- \left[p_o s(t_2)(1+\varepsilon_2)(w-z) \xi_2 (u-1) - u p_o \int_{t_2}^{\hat{t}_2} s(t)dt \right]$$
$$= \alpha(\varepsilon_0, \xi_0) - \alpha(\varepsilon_1, \xi_1) - \alpha(\varepsilon_2, \xi_2), \quad (23)$$

where $\alpha(\varepsilon_0, \xi_0)$, $\alpha(\varepsilon_1, \xi_1)$, and $\alpha(\varepsilon_2, \xi_2)$ represent the three terms in square brackets.

It can be shown that $\alpha(\varepsilon_0, \xi_0)$, $\alpha(\varepsilon_1, \xi_1)$, and $\alpha(\varepsilon_2, \xi_2)$ are positive terms. Therefore, the sign of Δ depends on the interplay between them. Among other factors, the absolute values of the estimation errors determine the relative magnitude of these terms and therefore affect the sign of Δ.

In particular, if the error terms are declining with the length of the forecasting horizon (i.e., $|\varepsilon_0| > |\varepsilon_2|$, $|\varepsilon_0| > |\varepsilon_1|$, $|\xi_0| > |\xi_2|$, $|\xi_0| > |\xi_1|$), then it is likely that $\alpha(\varepsilon_0, \xi_0) \gg \alpha(\varepsilon_1, \xi_1)$ and $\alpha(\varepsilon_0, \xi_0) \gg \alpha(\varepsilon_2, \xi_2)$, and hence $\Delta = f - f^* > 0$. However, if the errors fail to decline with the length of the forecasting horizon, then $\alpha(\varepsilon_0, \xi_0) < \alpha(\varepsilon_1, \xi_1)$ and/or $\alpha(\varepsilon_0, \xi_0) < \alpha(\varepsilon_2, \xi_2)$ and hence $\Delta = f - f^* < 0$.

In other words, if the refinement of the reassessment interval allows the volume uncertainty to be reduced, as reflected in the declining values of the estimation errors, then the economic benefit of the refinement is greater when the volume uncertainty is present. On the other hand, if the interval refinement fails to reduce the volume uncertainty, then the economic surplus due to the refinement becomes smaller. Let us illustrate it with the special case of the linearly growing demand function.

In the case of linear growth specified by the demand function in Eq. (12), the cost difference f is in the form

$$f = f^* + p_o(at_0+b)(1+\varepsilon_0) w (u-1)\xi_0$$
$$- p_o(at_1+b)(1+\varepsilon_1) z (u-1)\xi_1$$
$$- p_o(at_2+b)(1+\varepsilon_2)(w-z)(u-1)\xi_2$$
$$+ u p_o \times [-\frac{a}{2} t_0^2 \xi_0(\xi_0+2) - b\xi_0 t_0 + \frac{a}{2} t_1^2 \xi_1(\xi_1+2) + b\xi_1 t_1$$
$$+ \frac{a}{2}\left(z^2 + (t_2-z)^2(1+\xi_2)^2 + 2z(t_2-z)(1+\xi_2) - t_2^2\right)$$
$$+ b(z + (t_2-z)(1+\xi_2) - t_2)], \quad (24)$$

which can be rewritten as

$$f = f^* + p_o(u-1)$$
$$\times \left[\xi_0 w \left[(a\frac{u-1}{u} w + b)(1+\varepsilon_0) - w(\xi_0+2)\frac{a}{2}\frac{(u-1)}{u} - b \right] \right.$$
$$- \xi_1 z \left[(a\frac{u-1}{u} z + b)(1+\varepsilon_1) - z(\xi_1+2)\frac{a}{2}\frac{(u-1)}{u} - b \right]$$
$$- \xi_2 (w-z) \left[(a(z + \frac{u-1}{u}(w-z)) + b)(1+\varepsilon_2) \right.$$
$$\left.\left. - \frac{a}{2}\left(\frac{u-1}{u}(w-z)(\xi_2+2) + 2z\right) - b \right] \right] \quad (25)$$

or, equally, as

$$f = f^* + p_o(u-1) \times \left[\xi_0 w \left[a\frac{u-1}{2u} w(2\varepsilon_0 - \xi_0) + b\varepsilon_0 \right] \right.$$
$$- \xi_1 z \left[a\frac{u-1}{2u} z(2\varepsilon_1 - \xi_1) + b\varepsilon_1 \right]$$
$$\left. - \xi_2 (w-z) \left[a\frac{u-1}{2u}(w-z)(2\varepsilon_2 - \xi_2) + (az+b)\varepsilon_2 \right] \right]. \quad (26)$$

Observe that, for the linear growth function, it holds that

$$\xi_i = \varepsilon_i (1 + \frac{b}{at}) = k_i \varepsilon_i, \quad (27)$$

where $k_i = 1 + \frac{b}{at}$ is a function of t, $i = 1..3$. Further, let the errors ε_1 and ε_2 be expressed as functions of ε_0, i.e. $\varepsilon_1 = c_1 \varepsilon_0$ and $\varepsilon_2 = c_2 \varepsilon_0$, where c_1 and c_2 are real-valued coefficients. Then, the equation above can be rewritten as

$$f = f^* + p_o(u-1)\varepsilon_0^2 \times \left[k_0 w \left[a\frac{u-1}{2u} w(2-k_0) + b \right] \right.$$
$$- k_1 c_1 z \left[a\frac{u-1}{2u} z c_1(2-k_1) + c_1 b \right]$$
$$\left. - k_2 c_2 (w-z) \left[a\frac{u-1}{2u}(w-z)c_2(2-k_2) + c_2(az+b) \right] \right]. \quad (28)$$

Thus, if we assume that c_1 and c_2 are independent of ε_0, then $f - f^*$ is a quadratic function of ε_0 with an extremum at (0, 0). Among other factors, the sign of $f - f^*$ depends on a and c_2: if $c_2 \leq 1$ (i.e., if the errors are non-declining functions of the length of the forecasting horizon), then it is likely that $f - f^* > 0$. However, when $c_2 > 1$ and $a \gg 0$, then the last term in the equation above likely dominates, resulting in $f - f^* < 0$.

4. Numerical experiment: simulating an archival system

In the previous section, an artifact in the form of a hybrid cloud storage cost model has been introduced and analytically investigated, with the aim of revealing its inherent properties. This section expands our effort at evaluating this model by means of numerical simulations that take into account the context of a real-world organization.

4.1. Design of numerical experiments

Numerical simulation is a kind of simulation that relies on numerical methods to quantitatively represent the evolution of a physical system (Colombo and Rizzo, 2009). By analogy with laboratory experiments, these calculations with numerical models are referred to as numerical experiments (Bowman et al., 1993; Bacour et al., 2002; Winsberg, 2003). Each numerical experiment studies how a particular combination of input parameters affects the output parameter of interest, and the set of the experiments is designed to maximize the amount of relevant information from a limited number of simulation runs (Hunter et al., 1978). In order to resemble reality, the simulation needs to rely on the real demand for storage experienced by a real-world organization as well as on the real pricing for the private and public storage resources, as described below.

Demand for storage

The real demand for storage as experienced by the archival system of the National Center for Atmospheric Research and University Corporation for Atmospheric Research (NCAR & UCAR) is utilized in the experiments. This organization has been chosen for the study for three reasons. First, NCAR is an example of a real-world organization that maintains and develops a large-scale storage solution whose storage demand and its growth can be considered to be representative. Second, a long-time trace of storage massives in use at NCAR allows the historic developments of storage needs to be observed. Finally, as opposite to commercial organizations that keep their infrastructure details secret, the traces of storage growth at NCAR were publicly available for this study.

The historical development of the Archival System at NCAR is documented on the organization's website.[4] The NCAR's archival

[4] See the annual reports of the Computational & Information Systems Laboratory that manages the archival system; these are available at http://nar.ucar.edu/.

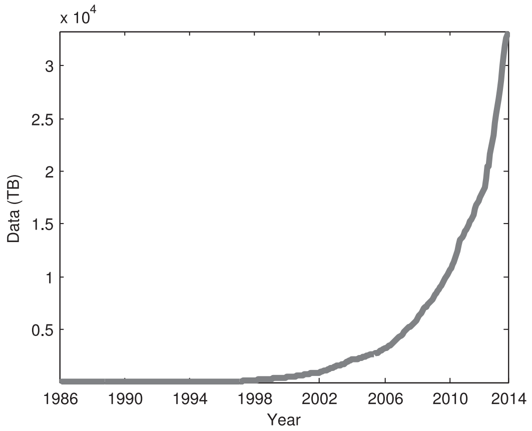


Fig. 5. Growth of the NCAR archiving storage during 1986–2014.

systems have their roots in the mid-1960s. Over the years, a number of developments were made to accommodate the growing needs for storage, either by expanding the available storage massives or by replacing them with more efficient solutions. Due to a constant need to evolve while providing service continuity, multiple storage technologies have co-existed within the NCAR's archival systems.[5] At present, the archival system represents a combination of the new tape libraries of High Performance Storage System (HPSS),[6] and the legacy tape libraries maintained by a subcontractor.[7] This tape-based archival storage is used in concert with the GLobally Accessible Data Environment (GLADE), the centralized disk-based storage service using high-performance GPFS shared file system technology.[8]

For the purposes of this study, we use the storage metrics with monthly granularity that were kindly provided by NCAR. In Fig. 5, the growth profile of the NCAR's archival system during the period 1 September 1986–1 April 2014 is shown. As evidenced by the figure, the demand for data storage exhibited exponential growth during these years, rising from 2TB in 1986 to over 30PB in 2014.

Public storage

The unit price of public storage can be estimated by, for example, consulting the price list of Amazon Web Services (AWS), one of the leading providers of public cloud infrastructure services (Leong et al., 2014).

Assuming that Reduced Redundancy Storage (RRS) is used as a public storage equivalent,[9] it costs $0.024, $0.0236, and $0.0232 per GB per month to store the first TB, the next 49 TB, and the next 450 TB of data, respectively. Further, transferring the data out of the cloud costs $0.12, $0.09, and $0.07 per GB for the first 10 TB, next 40 TB, and the next 100 TB, respectively. Note that, for simplicity, the request pricing has not been taken into account, because the contribution of the request-based charges to the overall cost is rather modest in the case of the archival solutions.

Instead of RRS, Amazon Glacier could have been used as an inexpensive public tape storage equivalent that only costs $0.01 to store 1 GB for a month. However, significant costs are incurred for transferring the data out of the service because, in addition to the data transfer fee above, the transfer may incur a significant retrieval fee that depends on the desired retrieval rate. Deleting files stored for less than three months incurs fees as well. All this makes the use of Glacier economically inefficient in cases where the data is stored for short periods of time, as is considered in the paper.

Private storage

The unit price of the private storage for newly designed storage solutions can be approximated using the costs incurred by Backblaze (Nufire, 2011). Specifically, in order to provision a PB of storage, in 2011 Backblaze was reportedly spending $94 563 over three years for hardware, space, power, bandwidth, and maintenance, which corresponds to $2.57 per TB per month. By 2014, the cost of storage hardware declined from $0.055 per GB in 2011 to $0.0517 per GB in 2014, owing to more efficient design and declining component prices (Klein, 2014); however, we will assume the total cost per TB unchanged due to a likely increase in other costs, such as rents and labor costs.

It should be noted that, along with the storage hardware, the software solutions for managing the storage (e.g., IBM Tivoli Storage Manager) and related services are also likely to be needed, thus increasing the cost of the storage solution further. However, we assume that these software and service costs are minor when compared to the other storage-related costs, and hence may be neglected for the sake of simplicity.

Utility premium

The value of the utility premium u varies depending on the type and the volume of storage to be provisioned as well as on the pricing set by the public cloud storage provider and the cost-efficiency of the private solution. For instance, storing 100 TB of data on disk over a six-month period cost: (i) $1539 if the data is stored in-house using Backblaze's type of storage, and (ii) $22,878 if the data is stored in Amazon Reduced Redundancy Storage and transferred at the end of the storage period; this results in a utility premium value of $22,878/$1539 = 14.9.

Storing the same volume of data on tape will cost (i) $2550 if the in-house tape storage is used as described in (Reine and Kahn, 2013), and (ii) $16,786 if Amazon Glacier is used instead,[10] thus resulting in a utility premium of $16,786/$2550 = 6.6.

A couple of issues should be noted at this point. The costs of the private storage solutions may be underestimated. First, additional labor costs are incurred to design, implement, and maintain growing in-house storage facilities. Second, additional costs will be required if higher redundancy level is needed, especially if geographically distributed facilities are deployed. Finally, for lower-scale data storage solutions, the absence of volume discounts is likely to increase the prices for the components. Due to these and possibly other factors, the value of the utility premium may be lower, but still notably greater than one.[11] We will therefore explore a set of different values of utility premium in the range of $u \in [4; 20]$.

It should also be mentioned that the reassessment cost (i.e., the cost associated with estimating the future demand for the next reassessment interval and acquiring and deploying additional in-house storage resources) greatly depends on the internal practices of the organization; its value therefore is difficult to estimate. Due

[5] See the mass storage technologies used at NCAR by 2006 at http://www.cisl.ucar.edu/nar/2006/links/2.3.mss.lg.jsp.

[6] https://www2.cisl.ucar.edu/docs/hpss

[7] http://www.nar.ucar.edu/2009/CISL/1comp/1.3.6.amstar.php

[8] https://www2.cisl.ucar.edu/resources/glade

[9] The details of RRS pricing are available at http://aws.amazon.com/s3/ the prices used in the research are for US Standard region and are valid on 2.8.2014.

[10] We further assume that the data is transferred from Amazon Glacier to the in-house storage solution at the end of the storage period, reserving two weeks for the retrieval.

[11] Otherwise, the in-house storage solutions would not be economically justifiable, as was shown analytically by Weinman (2011a)

to this, and also because this cost is likely to be insignificant in the case under consideration when compared with the overall storage costs for the case organization, in the numerical experiments below we assume the reassessment cost to be zero.

Finally, it should be pointed out that the prices for storage components and storage services tend to decline with time (Walker et al., 2010; Reine and Kahn, 2013; Jackson, 2014). However, we assume that approximately the same decline rate applies to both the private and the public portions. Likewise, the time value of money is not taken into account in the cost estimates, because, within a single reassessment interval, the present value of money changes insignificantly and has a limited effect on the overall costs.

In the simulation below, we compare the costs incurred by an organization facing the growing demand for storage as experienced by NCAR (i) in the case that the organization is re-estimating its storage needs and acquiring additional in-house resources on a yearly basis, and (ii) in the case when the organization is conducting the reassessment twice a year at different time points measured in months, $z \in \{2, 3, \dots, 11\}$.

4.2. Results

Let us consider the compound effect of the reassessment interval and the volume variation – reflected in the changing demand function and its forecasting inaccuracy – on the total cost of the hybrid cloud storage.

4.2.1. Known demand for storage

We first estimate the cost of hybrid cloud storage under the assumption that the future changes of the demand for storage are known in advance. In this case, as explained in the preceding section, both the time of using public cloud resources and the volume of the private storage to be acquired can be set to minimize the overall cost.

The cost estimate includes both the cost of storage as well as the data transfer cost. The data transfer cost is estimated based on the pricing of Amazon EC2, assuming that 5% of the stored data is requested and transferred monthly, and that the whole volume of the data in the public subsystem is transferred to the private subsystem. Furthermore, the effective value of the utility premium is estimated based on the total monthly volumes of storage. This estimate varies between 2.27 and 10.29, so the median value of $u = 2.88$ is therefore used in the cost calculations unless explicitly specified otherwise.

In Fig. 6, the total yearly costs of hybrid cloud storage are shown for the reassessment intervals of six and twelve months. In order to make the figure more readable, only the costs over the last six years (2008–2013) are shown. As the figure shows, the total hybrid storage costs are lower if the organization reassesses its storage needs more often, that is, once every six months instead of once a year. This is in line with Proposition 3.1, which claims that the more frequent re-evaluation of storage needs to be cost-beneficial.

According to Lemma 3.1, the cost saving function $f(z)$ has a single extremum in the interval $(0, w)$, which corresponds to the maximum of $f(z)$ in the region $(0, w)$. This is visible in Fig. 7, where the cost savings are portrayed as a function of the refinement point z. Furthermore, in line with Lemma 3.2, for linearly growing demand function, the greatest cost saving is expected when $z_{max} = w/2$, whereas for exponentially growing demand function, in line with Lemma 3.3, the value of z_{max} shifts to the right, $z_{max} > w/2$.

As can be seen from the graphs in Fig. 7, the greatest cost savings are achieved when the company reassesses its storage needs at the middle of the original reassessment period, in other words, if the refinement is done at $z = 6$ months given the original reassessment interval of $w = 12$ months. Thus, albeit the storage demand does exhibit an exponential growth and hence $z_{max} > w/2$ is expected, in practice, $z_{max} = w/2$ predicted for the linear growth is observed. This can be explained by the fact that, within a single year, the growth rate is relatively low (circa 0.03 in average), and hence the growth can be relatively well approximated with a linear function.

Finally, let us turn to the effect of the utility premium u on the cost savings. As stated in Lemma 3.4, the cost savings due to the refinement of the reassessment interval increase with the value of u. In order to investigate this dependency, Fig. 8 plots the dependency between the cost savings function f and the utility premium.

The graphs in the figure reflect the overall regularity expressed in Lemma 3.4: in the cost-optimal allocation of storage to the private and public cloud, the more expensive the public cloud is compared to the private cloud, the greater are the cost savings that can be achieved with reassessing the storage needs more often. Meanwhile, as can be seen from the figure, for some subregions of utility premium values the cost savings may remain constant or

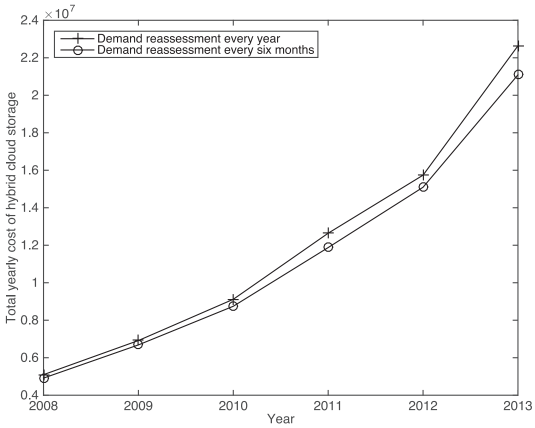


Fig. 6. The total yearly cost of a hybrid cloud storage for reassessment intervals of six and twelve months.

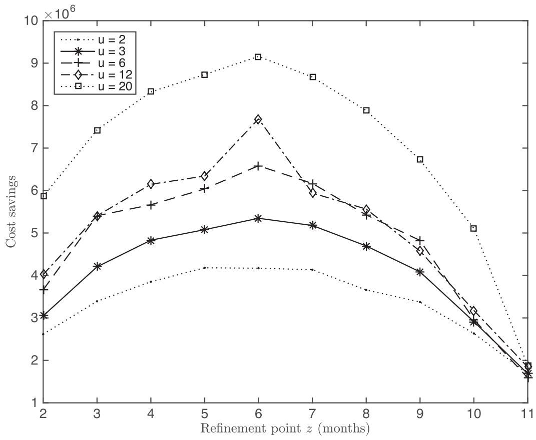


Fig. 7. Cost savings due to the refinement of the reassessment interval for different times of refinement.

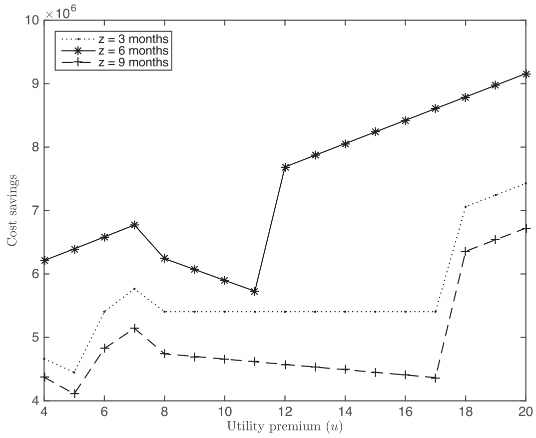


Fig. 8. Cost savings due to the refinement of the reassessment interval for different levels of utility premium u.

even decrease temporarily (e.g., consider the case of $z = 9$ and $8 \leq u \leq 17$). Such temporal declines are caused by the rounding of the time of public cloud storage use. Specifically, small changes in u induce a small change in the cost-optimal time of using the public cloud resources (i.e., $w - t_i$). However, since $w - t_i$ is calculated with monthly granularity and hence needs to be rounded to the nearest month, this results in suboptimal values of $w - t_i$, and consequently may result in a cost saving that is (temporally) decreasing with u. Note that the effect of this rounding is also visible in Fig. 7, where, for $u = 2$, $z_{max} = 5$, while $z_{max} \geq 6$ is expected.

4.2.2. Forecasted demand for storage

Let us now turn to the case when the future demand for storage is not known and is therefore forecasted based on the traces of demand observed in the past. As in the previous experiment, here we consider the compound effect of the reassessment interval and the volume variation on the total cost of the hybrid cloud storage. However, whereas in the preceding experiment the volume variation was limited to the changing demand function, in this numerical experiment, the more realistic settings are studied by considering the volume variation as reflected in both the changing demand function and its forecasting inaccuracy.

Specifically, this experiment relies on forecasting the future demand at the beginning of every reassessment period based on the historical data. The forecasting is performed by using the non-linear least square fitting to estimate the parameters of an exponential growth function. The forecasted and the original data for yearly reassessment interval are shown in Fig. 9. As can be seen from the figure, the forecasted demand curve largely follows the original demand, although there are periods when the demand is under- or overestimated. In the results presented next, we have excluded the data for the first year because there was no historical data to base the forecast on. We have also excluded the data for the final year (2014) because the available data for that year were incomplete.

As was analytically shown in the previous section, the effect of the refinement of the reassessment interval on the cost savings depends on whether the forecasting inaccuracy decreases with the refinement. Indeed, as Fig. 10 and Table 2 show, the change in the cost savings Δ greatly correlates with the change in the estimation errors: for 21 years out of 26, the sign of Δ matches the sign of $\varepsilon_0 - \varepsilon_2$. Furthermore, in the cases when $\varepsilon_0 \approx \varepsilon_2$ (i.e., more formally, when $|\varepsilon_0 - \varepsilon_2| < 0.01$), the sign of Δ depends on the change of the time estimation error ξ: when ξ declines or remains the same after refinement ($\xi_0 - \xi_2 \leq 0$), the cost difference increases (in 2001 and 2002), whereas for the years when the error increases ($\xi_0 - \xi_2 > 0$), the cost difference declines (in 2011 and 2012). Thus, in line with the analytical considerations in Section 3.3, it can be observed that, while the refinement of the reassessment interval does cut the cost of hybrid storage, the magnitude of the cost cut further depends on the inaccuracy of the demand forecasting; in particular, when the refinement allows the estimation errors to be reduced, the cost reduction increases. Otherwise, it decreases.

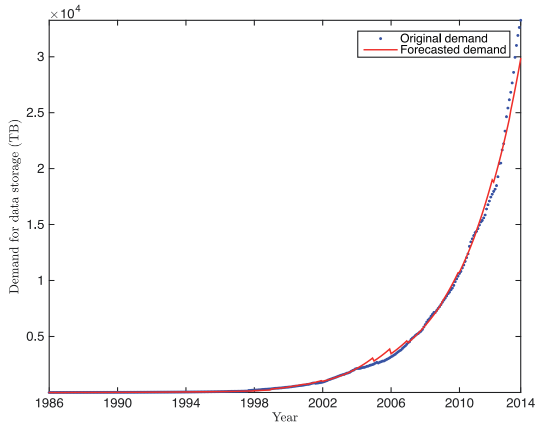


Fig. 9. Forecasted and real storage growth.

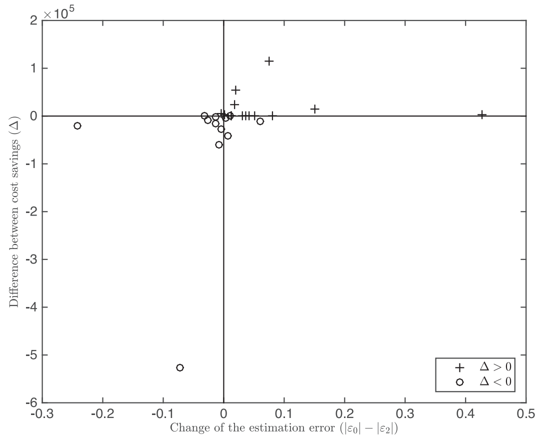


Fig. 10. Change in the cost savings (Δ) vs. the change in the demand estimation error ($|\varepsilon_0| - |\varepsilon_2|$).

There is also an interesting phenomenon worth mentioning. In the case that (i) the demand function is growing stepwise, (ii) the stepwise growth co-occurs with t_i, and (iii) a small overestimation of demand is present, then the presence of the overestimation has no impact on the estimation of t_i. Specifically, given two consecutive steps of the demand function s_x and s_{x+1} occurring at t_i, and given a small estimation error ε_i s.t. $s_x(1 + \varepsilon_i) < s_{x+1}$, the cost impact of the overestimation can be expressed as:

Table 2
Estimation errors and the change in cost savings.

Year	ε_0	ε_1	ε_2	ξ_0	ξ_1	ξ_2	Δ
1988	0.620	0.325	0.192	0.50	0.50	0.50	2062.88
1989	0.096	0.097	0.044	0.50	0.25	0.50	186.97
1990	0.158	0.067	0.126	0.50	0.50	0.50	501.39
1991	0.136	0.107	0.056	0.50	0.50	0.50	259.59
1992	0.036	0.010	0.023	0.13	0.00	0.00	63.12
1993	0.019	0.007	0.050	0.13	0.00	0.50	−16.17
1994	0.104	0.074	0.067	0.50	0.50	0.50	−144.51
1995	0.091	0.069	0.049	0.38	0.50	0.50	183.90
1996	0.045	0.036	0.032	0.25	0.25	0.25	123.04
1997	−0.013	0.036	−0.027	−0.13	0.25	−0.50	90.20
1998	−0.031	−0.007	−0.273	−0.25	−0.25	−0.50	−20,252.56
1999	−0.292	−0.253	−0.143	0.50	−1.00	−1.00	15,570.07
2000	−0.026	−0.058	0.023	−0.25	−0.50	0.00	−4537.85
2001	0.066	0.047	0.064	0.25	0.25	0.25	2478.82
2002	0.112	0.055	0.117	0.50	0.25	0.50	5247.23
2003	−0.005	0.040	−0.032	−0.13	0.00	−0.25	−8441.47
2004	0.013	−0.002	0.002	0.00	−0.25	0.00	−580.63
2005	0.159	0.085	0.138	0.50	0.50	0.50	55,074.42
2006	0.226	0.167	0.150	0.50	0.50	0.50	115,820.24
2007	0.093	0.095	0.032	0.25	0.50	0.25	−10,105.75
2008	0.005	−0.015	0.018	0.00	−0.25	0.00	−16,279.51
2009	−0.005	−0.023	0.009	−0.25	−0.50	0.00	−27,617.11
2010	0.038	0.016	0.019	0.13	0.00	0.00	24,527.86
2011	−0.023	0.016	−0.030	−0.13	0.00	−0.50	−60,162.71
2012	0.050	0.024	0.043	0.25	0.50	0.50	−41,240.11
2013	0.000	0.048	−0.073	−0.13	0.00	−0.50	−527,163.54

$$p_o s_x(1+\varepsilon_i)w - up_o s_x(1+\varepsilon_i)(w-\hat{t}_i)$$
$$= p_o s_x(1+\varepsilon_i)\left(w - u\left(w - \frac{u-1}{u}w\right)\right) = 0.$$

As a result, whenever such conditions occur, the corresponding term in Eq. (23) nullifies (i.e., $\alpha(\varepsilon_i, \xi_i) = 0$), which may have a decisive effect on the sign of Δ. This is the case, for instance, for 2004 and 2008, when $\alpha(\varepsilon_0, \xi_0) = 0$, resulting in $\Delta < 0$, as well as for 1992 and 2010, when $\alpha(\varepsilon_2, \xi_2) = 0$, resulting in $\Delta > 0$.

5. Discussion

Neoclassical economics can provide an apt characterization for the case of concurrent sourcing in the cloud storage domain. In it, the technology is commonly available with little asset specificity, partner behavior is predictable and so requires little protection against supplier opportunism, performance is predictable, and one of the central problems is how to operate at optimal scale and scope under volume uncertainty. Harrigan (1986), for instance, suggests that a mix of internal production and external suppliers is a low-risk strategy when demand is erratic and uncertain. Likewise, Carlton (1979) argues that it is advantageous to integrate in order to save costs for the high probability component of demand and use external suppliers for the low-probability demand.

In fact, the cloud storage domain represents a case which Parmigiani hypothesized but did not confirm in her study (Parmigiani, 2007). That is, a greater scope of economies for both the firm and its suppliers to produce the good was hypothesized to encourage the firm to concurrently source part of the demand. On the one hand, making everything internally would require prior investment based on estimated demand and create extra costs for unused capacity, while unpredictable volumes raise costs and hurt performance (cf. Wagner and Bode, 2006). On the other hand, the premium charged by the external suppliers for the surplus capacity is high: The standard neoclassical economic explanation for concurrent sourcing involves hedging against demand uncertainty. In this case, a firm can keep its internal plant at full production by using suppliers to handle fluctuating additional volumes, thereby running more efficiently due to having this flexibility in capacity (Adelman, 1949; Carlton, 1979; Porter, 1980). This position assumes a robust spot market with a large number of qualified external suppliers vying for the firm's business, although these suppliers will have higher base costs (Adelman, 1949). The actual prices they charge the firm may be even higher, due to the risk they are bearing by having unused capacity during slack times and by not knowing when the 'low probability' demand will occur (Carlton, 1979). Indeed, suppliers may charge premiums for lower volumes and short lead times since they know they are merely 'overflow outlets' for the firm (Harrigan, 1986; Hill, 1994). Firms may be willing to pay these premiums rather than invest in additional, and potentially underutilized, capacity. (Parmigiani, 2007) In fact, unlike many other previous studies summarized in Mols (2010) and Parmigiani (2007), the neoclassical theory alone seems to provide the most applicable explanation for the concurrent sourcing problem in hybrid cloud storage.

Prior literature has shown that concurrent sourcing in the context of cloud resources, referred to as the hybrid cloud, can reduce costs by combining in-house processing and storage capacity with premium-priced public cloud capacity. This paper has shown that the cost of hybrid cloud storage in concurrent sourcing may be reduced even more by refining the reassessment interval. Furthermore, the magnitude of the cost cut depends on two distinct dimensions of volume variation: on the non-stationary (demand variability) and on the non-deterministic nature of the demand volume (demand volume uncertainty). The findings are the following:

- For demand variability: The maximum cost cut is achieved when the refinement is at the middle of the sourcing period, for linear growth, and the cost cut grows with the utility premium.
- For demand volume uncertainty: If the refinement allows the forecasting inaccuracy to be reduced, then the economic benefit of the refinement increases. Otherwise, it decreases.

Note that the results on demand variability are specific to hybrid cloud storage and they do not necessarily hold true, for example, in the context of hybrid cloud computing resources. This is due to the monotonically growing nature of the storage demand, which makes the variability decline if the reassessment interval gets shorter. Meanwhile, the results regarding demand volume uncertainty are generally applicable to hybrid cloud computing resources as well, and are likely to be applicable to the other domains where concurrent sourcing is used.

Based on the analytical findings (see Lemma 3.5), re-estimating future storage needs more often and acquiring additional in-house resources accordingly reduces the total hybrid cost, assuming no additional cost associated with the reassessment. However, this additional cost – the reassessment cost – reduces the cost benefits. It follows that refining the reassessment interval can be recursively continued and cost-benefits achieved until the cost associated with demand estimation and additional in-house resource provisioning exceed these benefits.

Based on the numerical example with NCAR's archival system data, moving from twelve-month cycles in storage capacity acquisition of hybrid cloud storage resources to six-month cycles would decrease the annual costs by about $1M, representing about 5% of the annual $23M in costs for 2013. Meanwhile, when compared to the costs of acquiring new resources only, the cost benefit of shortening the acquisition interval grows to about 15% of the acquisition expenses. In this example, the demand estimation errors were relatively small, in most years resulting in an impact on the savings volume that was between plus or minus $ 50K (i.e., less than 3%). However, due to the nature of a business, the estimation error can easily be much higher than in this example.

We should note that the demand for storage in the case of NCAR exhibits annual growth of 40%, a figure in line with the general growth trend reported for digital storage (IDC, 2014). Therefore, the results are expected to be applicable to other organizations engaging in the adoption of hybrid cloud storage. However, care should be taken when extrapolating the findings above to other domains of concurrent sourcing, where the specifics of these domains, including the growth trend and its predictability as well as the utility premium values, should be taken into account.

The case considered in this paper further connects concurrent sourcing to the literature on strategic flexibility (Sanchez, 1995), especially that regarding resource flexibility (Sanchez, 2004) and real options (Brydon, 2006) as well as relates to transaction cost economics (Williamson, 1985). As long as we assume no extra cost from repeating the capacity estimation and acquisition cycle more often, the faster cycle provides an option to minimize the sum of volume diseconomies and utility premium of resource vendors as well as revise the acquisition plan to mitigate estimation errors. The additional costs related to extra acquisition cycles can in this case be compared with the savings representing 15% or $1M for halving the cycle for the case organization. However, even though in an organization of this size, the benefits exceed the costs, for a small organization the savings could easily be smaller than the resource acquisition costs, thus recommending the use of an annual capacity acquisition cycle.

6. Conclusions

The core benefit of cloud computing can be attributed to the business flexibility achievable by converting capital IT expenditures to on-demand operational expenditures. As compared with traditional in-house IT infrastructure, this provides both a low-cost option to scale a business and the ability to make frequent and rapid changes in business models. This flexibility has been essential to the emergent trend to utilize cloud-based capacity, transform the IT function to cloud-compatible systems, and utilize agile networked business models. In order to deliver such flexibility, public cloud providers have to be capable of guaranteeing scalability for services whose demand grows by factors of 100 or even 1000 in a few months. In response, these providers may request utility premiums as high as 2–20 times the in-house costs.

The hybrid cloud solutions combining fixed in-house cloud resources and flexible public cloud resources provide cost-optimal solutions when the volume variation is high. In such cases, the cost can be minimized by serving the high probability component of demand with in-house resources and by using the public cloud for the peak demand only. Significantly, the need to communicate between in-house cloud resources and public cloud resources reduces the benefit of using public cloud resources. This implies that the cloud storage associated with cloud computing capacity may be a critical factor limiting the benefits of cloud adoption.

This paper contributes to the cloud storage economics literature by analyzing hybrid cloud storage, which combines in-house storage and public cloud storage. A general hybrid storage cost model was constructed to analyze the cost benefits of using hybrid cloud storage in the presence of volume variation. Specifically, these cost benefits were analyzed in the presence of demand variability, as manifested in seasonal changes, and in the presence of volume uncertainty, as manifested in the volume estimation errors. This analysis shows that shortening the reassessment interval and more frequent acquisition of private cloud storage capacity allows the volume variability to be reduced, yielding a reduction of the overall costs. We further showed that splitting an in-house resource acquisition interval into equal subintervals maximizes the cost saving, assuming that the demand needs grow linearly. The analytical part was validated with a numerical example from a conventional storage organization. Namely, the data from NCAR's archival system showed that cutting the resource acquisition cycle from twelve months to six months would provide 15% acquisition cost savings, with the assumption that there would be no costs for speeding up the storage acquisition cycle.

Importantly, this paper sheds some light on the economic viability of organizational transformation towards cloud adoption through re-engineering or replacing an organization's information systems to become hybrid cloud-enabled. Indeed, the economical viability of cloud transformation can be questioned for a number of reasons: the renewal of information systems incurs costs, using cloud-enabled software includes a performance penalty (5–15%), and the use of public cloud offerings is associated with high utility premiums. Such a high premium is tolerable for small firms with no in-house IT capability, but for larger enterprises with in-house IT capabilities the use of the resources available in-house may prove less expensive in the longer term.

When we assume no costs for such a cloud transformation, this paper's analytical model explains how the optimal cost of cloud storage can be achieved by using concurrent sourcing (i.e., the combination of in-house private cloud and a limited volume of public cloud). In the numerical example from a conventional storage organization, cutting the annual resource acquisition cycle to six months would provide 15% savings on cloud storage costs, assuming no costs for speeding up the storage acquisition cycle and executing it twice a year. This cost saving may represent an incentive for an enterprise to acquire the capability needed for concurrent sourcing in cloud environments, that is, for adopting a cloud platform internally to be able to gain the cost benefit of the hybrid cloud solution through concurrent sourcing. In short, the cost benefit of flexibility in concurrent sourcing could motivate an enterprise to carry out a cloud transformation.

These results encourage enterprises to enable the use of a hybrid cloud approach through conformance to standards and the development of in-house competences, and thus promote the development of capability for performing cost-efficient cloud storage acquisition. From the perspective of Schlagwein et al. (2014), the results support the trend toward ensuring technological cloud readiness in enterprises. This readiness can support immediate or long-term migration of applications to the cloud as well as enable flexible, short-term contracts with cloud providers while allowing enterprises to retain internal capabilities in their IT functions and become competent IT brokers able to integrate external and internal IT resources. In other words, they become able to support hybrid cloud storage solutions.

While this paper showed that the cost benefit of flexibility in concurrent sourcing motivates an enterprise like the case organization to adopt a hybrid cloud approach which requires in-house cloud capability and cloud transformation of incumbents, the case could be somewhat different in new ventures with extreme volume variation. They need not carry the legacy IT with them and can build cloud-enabled IT infrastructure from the beginning, leading to a reduction in the cost of the transformation. For small firms the overhead of establishing in-house information systems, maintaining in-house servers, and so on may also be a capital-intensive cost factor that can or even must be avoided. They may therefore have the tendency to use only the public cloud until the storage demand has increased substantially and the cost benefit of a hybrid cloud approach overrules the capital expenditure and inflexibility of in-house storage. To further understanding of this practice, we suggest that future research address the economic view on the flexibility and premium costs of the public cloud-only approach in comparison to the cost-optimal hybrid cloud solution in quickly growing small enterprises with high volume variation.

Appendix A. Cost factors in hybrid cloud infrastructure (Table A.3)

Appendix B. Proofs of the propositions

B1. Proof of Proposition 3.1

Proof. Let $F(t)$ be an antiderivative of $s(t)$. In this case, Eq. (11) can be rewritten as follows:

$$f = u\,p_o\left(F(w) - F\left(\frac{u-1}{u}w\right) - F(z) + F\left(\frac{u-1}{u}z\right) - F(w) + F\left(z + \frac{u-1}{u}(w-z)\right)\right)$$
$$= u\,p_o\left(F\left(z + \frac{u-1}{u}(w-z)\right) - F\left(\frac{u-1}{u}w\right) + F\left(\frac{u-1}{u}z\right) - F(z)\right)$$
$$= u\,p_o\left(\int_{\frac{u-1}{u}w}^{z+\frac{u-1}{u}(w-z)} s(t)dt - \int_{\frac{u-1}{u}z}^{z} s(t)dt\right). \tag{B.1}$$

Having introduced an auxiliary function $g(t) = s(t + \frac{u-1}{u}(w-z))$, Eq. (B.1) can be further rewritten in the form

$$f = u\,p_o\left(\int_{\frac{u-1}{u}z}^{z} g(t)dt - \int_{\frac{u-1}{u}z}^{z} s(t)dt\right). \tag{B.2}$$

Since $w > z$, it follows that $g(t) > s(t)$. Using the property of integral monotonicity, it further follows that $f > 0$, and thus re-evaluating the storage needs more often reduces the overall hybrid cloud storage cost. □

B2. Proof of Lemma 3.1

Proof. Based on Eq. (B.1), the first derivative of f with respect to z can be obtained:

$$\frac{\partial f}{\partial z} = u\,p_o\left(\frac{\partial}{\partial z}F(t_2) + \frac{\partial}{\partial z}F(t_1) - \frac{\partial}{\partial z}F(z)\right)$$
$$= u\,p_o\left(\frac{1}{u}s(t_2) + \frac{u-1}{u}s(t_1) - s(z)\right). \tag{B.3}$$

It can be shown that, in the interval $(0, w)$, f has only one extremum point where $\frac{\partial f}{\partial z} = 0$.

Let us rewrite the partial derivative in the form:

$$\frac{\partial f}{\partial z} = u\,p_o\,s(z)\left(\frac{1}{u}\frac{s(t_2)}{s(z)} + \frac{u-1}{u}\frac{s(t_1)}{s(z)} - 1\right). \tag{B.4}$$

It can be seen that $\frac{\partial f}{\partial z} = 0$ iff the condition holds that

$$\frac{1}{u}\frac{s(t_2)}{s(z)} + \frac{u-1}{u}\frac{s(t_1)}{s(z)} = 1. \tag{B.5}$$

Observe that if $z \to 0$, then $t_1 \to 0$ and $s(t_1) \approx s(z)$. Furthermore, since $s(t_2) > s(z)$, it can be easily seen that

$$\frac{1}{u}\frac{s(t_2)}{s(z)} + \frac{u-1}{u}\frac{s(t_1)}{s(z)} > 1, \tag{B.6}$$

and therefore $\frac{\partial f}{\partial z} > 0$.

Similarly, if $z \to w$, then $t_2 \to w$ and $s(t_2) \approx s(w) \approx s(z)$. In this case, since $s(t_1) < s(w)$, it can be easily seen that

$$\frac{1}{u}\frac{s(t_2)}{s(z)} + \frac{u-1}{u}\frac{s(t_1)}{s(z)} < \frac{1}{u} + \frac{u-1}{u}\frac{s(w)}{s(z)}, \tag{B.7}$$

and therefore

$$\frac{1}{u}\frac{s(t_2)}{s(z)} + \frac{u-1}{u}\frac{s(t_1)}{s(z)} < 1, \tag{B.8}$$

and it follows that $\frac{\partial f}{\partial z} < 0$.

Given a monotonically increasing demand function $s(t)$, the left part of the Eq. (B.5) is a monotonically decreasing function in the range $(\frac{1}{u} + \frac{u-1}{u}\frac{s(w)}{s(z)}, q)$, where $\frac{1}{u} + \frac{u-1}{u}\frac{s(w)}{s(z)} < 1$ and $q > 1$. Therefore, there exists a single value $z_{\max}$ in the interval $(0, w)$ satisfying Eq. (B.5). Furthermore, since the derivative changes its sign, $f > 0$ (based on Proposition (3.1)) and since a single extremum point exists at $z_{\max}$, it follows that this extremum corresponds to the maximum of f in the region $(0, w)$. □

B3. Proof of Lemma 3.2

Proof. Taking the derivative of the function in Eq. (13) with respect to the refinement point z, we get

$$\frac{\partial f}{\partial z} = p_o\,\frac{a\,(u-1)\,(w-2z)}{u}. \tag{B.9}$$

Taking the second derivative of the function Eq. (13) with respect to the refinement point z, we get

$$\frac{\partial^2 f}{\partial z^2} = -2\,p_o\,\frac{a\,(u-1)}{u}. \tag{B.10}$$

Since $p_o > 0$, $a > 0$ and $u > 1$, it follows that $\frac{\partial^2 f}{\partial z^2} < 0$ and f is concave. The critical point z_{max} where $\frac{\partial f}{\partial z} = 0$ is a maximum point:

$$z_{max} = \frac{w}{2}. \tag{B.11}$$

Because the function f is positive for every $0 < z < w$, at this point the cost savings are the greatest. □

B4. Proof of Lemma 3.3

Proof. Consider the exponentially growing demand function in the form

$$s(t) = e^{a\,(\tau+t)+b}, \tag{B.12}$$

where τ is the beginning of the reassessment interval prior to refinement, and where $a > 1$ (if the demand is monotonically

Table A.3
Cost factors reported in the literature on hybrid cloud infrastructure.

Cost factor	References
Cost factors related to the use of in-house resources	
Hardware (servers, network devices, lifetime of hardware, replacement costs of different hardware components)	Khajeh-Hosseini et al. (2012); 2011); Risch and Altmann (2008); Kashef and Altmann (2012); Tak et al. (2011); Kondo et al. (2009); Opitz et al. (2008); Greenberg et al. (2008); Koomey et al. (2007); Han (2011); Brumec and Vrček (2013); Bibi et al. (2012); Mastroeni and Naldi (2011); Walker et al. (2010); Mazhelis and Tyrväinen (2011); 2012); Mazhelis et al. (2012b); Beaty et al. (2011); Laatikainen et al. (2014); Mazhelis et al. (2012a); Gonzalez et al. (2013)
Electricity (cooling, lightning, electronic devices)	Khajeh-Hosseini et al. (2012); 2011); Risch and Altmann (2008); Kashef and Altmann (2012); Tak et al. (2011); Kondo et al. (2009); Armbrust et al. (2010); Opitz et al. (2008); Greenberg et al. (2008); Koomey et al. (2007); Han (2011); Bibi et al. (2012); Mastroeni and Naldi (2011); Walker et al. (2010); Mazhelis et al. (2012b); Beaty et al. (2011); Laatikainen et al. (2014); Mazhelis et al. (2012a); Gonzalez et al. (2013)
Software costs (basic server software, middleware, application software)	Andrikopoulos et al. (2013); Kashef and Altmann (2012); Risch and Altmann (2008); Kondo et al. (2009); Opitz et al. (2008); Tak et al. (2013); Bibi et al. (2012); Mazhelis and Tyrväinen (2011); 2012); Mazhelis et al. (2012b); Beaty et al. (2011); Laatikainen et al. (2014); Mazhelis et al. (2012a)
Labor costs (software and hardware maintenance, other support)	Kashef and Altmann (2012); Tak et al. (2011); Kondo et al. (2009); Opitz et al. (2008); Koomey et al. (2007); Han (2011); Bibi et al. (2012); Mastroeni and Naldi (2011); Walker et al. (2010); Beaty et al. (2011); Laatikainen et al. (2014); Mazhelis et al. (2012a); Gonzalez et al. (2013)
Business premises (air conditioner, rack, cabling, facility, internet connectivity, land, interest during construction, architectural and engineering fees, security, taxes, lifetime of data center, tier level of functionality, usable uninterruptible power supply (UPS) output, the electrically active floor area, insurance, etc.)	Kashef and Altmann (2012); Tak et al. (2011); Kondo et al. (2009); Armbrust et al. (2010); Hajjat et al. (2010); Truong and Dustdar (2010); Greenberg et al. (2008); Koomey et al. (2007); Opitz et al. (2008); Han (2011); Bibi et al. (2012); Turner and Seader (2006); Mazhelis and Tyrväinen (2011); 2012); Mazhelis et al. (2012a)
In-house resource utilization degree	Opitz et al. (2008); Mazhelis (2012); Tak et al. (2013); Greenberg et al. (2008); Koomey et al. (2007)
Acquisition interval (time period between two acquisitions of additional in-house resources)	Mazhelis (2012); Laatikainen et al. (2014); Mazhelis et al. (2012a)
Forecasting, provisioning, de-provisioning and demand monitoring interval	Weinman (2011c); 2011a)
Cost factors related to the use of public resources	
Computation costs (running virtual machine hours/CPU hours/server usage)	Khajeh-Hosseini et al. (2012); 2011); Risch and Altmann (2008); Andrikopoulos et al. (2013); Kashef and Altmann (2012); Tak et al. (2011); Kondo et al. (2009); Hajjat et al. (2010); Truong and Dustdar (2010); Hernández et al. (2013); Martens et al. (2012); Mian et al. (2012); Han (2011); Martens and Teuteberg (2012); Brumec and Vrček (2013); Kratzke (2012); Bibi et al. (2012); Mazhelis (2012); Mazhelis and Tyrväinen (2011); 2012); Mazhelis et al. (2012b); Weinman (2011b); 2011a); Truong and Dustdar (2010); Agarwala et al. (2011); Gonzalez et al. (2013); Adams et al. (2009)
Storage costs	Khajeh-Hosseini et al. (2012); 2011); Risch and Altmann (2008); Andrikopoulos et al. (2013); Kashef and Altmann (2012); Kondo et al. (2009); Armbrust et al. (2010); Hajjat et al. (2010); Truong and Dustdar (2010); Hernández et al. (2013); Martens et al. (2012); Mian et al. (2012); Martens and Teuteberg (2012); Kratzke (2012); Mastroeni and Naldi (2011); Walker et al. (2010); Mazhelis (2012); Mazhelis and Tyrväinen (2011); 2012); Mazhelis et al. (2012b); Truong and Dustdar (2010); Laatikainen et al. (2014); Mazhelis et al. (2012a); Agarwala et al. (2011); Ruiz-Alvarez and Humphrey (2011); 2012); Gonzalez et al. (2013); Adams et al. (2009)
Cost of input/output requests	Khajeh-Hosseini et al. (2012); 2011); Risch and Altmann (2008); Andrikopoulos et al. (2013); Kashef and Altmann (2012); Kondo et al. (2009); Martens et al. (2012); Martens and Teuteberg (2012); Kratzke (2012); Mazhelis (2012); Mazhelis and Tyrväinen (2011); 2012); Mazhelis et al. (2012b); Truong and Dustdar (2010); Mazhelis et al. (2012a); Agarwala et al. (2011); Gonzalez et al. (2013); Adams et al. (2009)
Cost of data in/out	Khajeh-Hosseini et al. (2012); 2011); Risch and Altmann (2008); Andrikopoulos et al. (2013); Kashef and Altmann (2012); Kondo et al. (2009); Armbrust et al. (2010); Hajjat et al. (2010); Truong and Dustdar (2010); Opitz et al. (2008); Martens et al. (2012); Mian et al. (2012); Martens and Teuteberg (2012); Kratzke (2012); Mazhelis (2012); Mazhelis and Tyrväinen (2011); 2012); Mazhelis et al. (2012b); Truong and Dustdar (2010); Mazhelis et al. (2012a); Agarwala et al. (2011); Gonzalez et al. (2013); Adams et al. (2009)
Cost of message queuing service, such as Amazon Simple Queue Service (decoupling the components of a cloud application)	Hernández et al. (2013)
Cost of load balancing	Hernández et al. (2013); Mazhelis (2012)
Cost of Domain Name System (DNS) web service, such as Amazon Route 53	Hernández et al. (2013)
Pricing models and utility premium of the cloud provider	Mazhelis (2012); Mazhelis and Tyrväinen (2012); Weinman (2011b); 2011a); Laatikainen et al. (2014); Mazhelis et al. (2012a); Agarwala et al. (2011)
Charging/billing period of the cloud provider	Mazhelis (2012); Laatikainen et al. (2014); Mazhelis et al. (2012a)
Data compression method (incl. compression ratio, compression and decompression time)	Agarwala et al. (2011)
Geographical redundancy, auditing and monitoring systems	Gonzalez et al. (2013)
Volume discount	Brumec and Vrček (2013); Mazhelis (2012); Mazhelis and Tyrväinen (2012)

(*continued on next page*)

Table A.3 (*continued*)

Cost factor	References
Costs factors depending on the interaction between the private and public cloud	
Allocation and partitioning costs	Tak et al. (2013); Martens and Teuteberg (2012)
Split between the private and public portions of the infrastructure	Mazhelis (2012)
Intensity of data communication between private and public portion of the cloud	Mazhelis (2012); Mazhelis and Tyrväinen (2011); 2012)
Time of using the public portion of the cloud	Mazhelis (2012); Mazhelis and Tyrväinen (2011); 2012); Weinman (2011b); 2011a)
Cost factors related to the organizational/environmental/system context	
System and service usage pattern (demand, usage duration and intensity, workload intensity and variance in workload intensity, infrastructure resource requirements, number of users, number of requests, data access frequency)	Andrikopoulos et al. (2013); Kondo et al. (2009); Klems et al. (2009); Kratzke (2012); Bibi et al. (2012); Mastroeni and Naldi (2011); Mazhelis (2012); Mazhelis and Tyrväinen (2011); 2012); Mazhelis et al. (2012b); Weinman (2011c); 2011b); 2011a); Laatikainen et al. (2014); Mazhelis et al. (2012a); Tak et al. (2013); Risch and Altmann (2008); Truong and Dustdar (2010); Kashef and Altmann (2012); Klems et al. (2009); Misra and Mondal (2011); Agarwala et al. (2011); Adams et al. (2009)
Storage growth rate	Tak et al. (2013); Brumec and Vrček (2013); Mastroeni and Naldi (2011); Laatikainen et al. (2014); Mazhelis et al. (2012a); Gonzalez et al. (2013)
Demand predictability	Mazhelis (2012); Weinman (2011c); 2011a); Laatikainen et al. (2014); Mazhelis et al. (2012a); Kashef and Altmann (2012); Klems et al. (2009); Adams et al. (2009)
Application type (Sequential or multi-threaded program, Parallel/MPI programs on multiple machines, workflows), application complexity, performance changes, possible security vulnerability, various time delay	Truong and Dustdar (2010); Tak et al. (2013)
Application requirements (e.g. runtime environment, database technology, software, load-balancing and redundancy requirements, security, data availability, reliability, scalability, Quality of Service, data sensitivity, work criticality, likelihood of reuse the data)	Klems et al. (2009); Laatikainen et al. (2014); Mazhelis et al. (2012a); Misra and Mondal (2011); Gonzalez et al. (2013); Adams et al. (2009)
System architecture (loadbalancing, autoscaling, processing, storage and backup tier structure, service dependency)	Kratzke (2012); Truong and Dustdar (2010)
Enterprise size / size of IT resources	Walker et al. (2010); Misra and Mondal (2011)
Technological advances/trends (e.g. growing disk capacity)	Brumec and Vrček (2013); Mastroeni and Naldi (2011); Adams et al. (2009)
Pricing/market trends	Walker et al. (2010); Mastroeni and Naldi (2011); Mazhelis (2012); Mazhelis and Tyrväinen (2012); Adams et al. (2009)
Other cost factors pertaining to the lifecycle of a cloud-based system	
Cost of strategic decision making (incl. identifying the application and infrastructure requirements, technology suitability analysis and stakeholder impact analysis) on adopting the hybrid cloud	Martens et al. (2012); Khajeh-Hosseini et al. (2012); Mazhelis et al. (2012b); Brumec and Vrček (2013)
Cost of evaluation and selection of service provider, SLA analysis and negotiation costs	Martens et al. (2012); Martens and Teuteberg (2012); Brumec and Vrček (2013); Mazhelis et al. (2012b); Adams et al. (2009)
Costs related to implementation, configuration, customization, integration and migration (incl. cost of migrating an application to cloud on infrastructure level, cost of software porting to the programming API exposed by a cloud, cost related to the transition period when both legacy and cloud environment co-exist)	Sun and Li (2013); Tak et al. (2013); Martens et al. (2012); Martens and Teuteberg (2012); Bibi et al. (2012); Mazhelis et al. (2012b); Beaty et al. (2011); Gonzalez et al. (2013)
Costs related to support and maintenance (hardware, software, ex post administration and coordination of the sourcing contracts and SLAs)	Martens et al. (2012); Martens and Teuteberg (2012); Bibi et al. (2012); Walker et al. (2010); Mazhelis et al. (2012b); Gonzalez et al. (2013)
Costs related to user training	Martens et al. (2012); Bibi et al. (2012); Mazhelis et al. (2012b)
Losses/benefits related to change in QoS (e.g. productivity gains or losses, confidentiality loss, availability loss, integrity loss due to system failure, downtime, security incidents)	Martens et al. (2012); Martens and Teuteberg (2012); Mazhelis et al. (2012b); Beaty et al. (2011); Mian et al. (2012); Khajeh-Hosseini et al. (2011); Misra and Mondal (2011); Adams et al. (2009)
Cost of vendor lock-in, cost of switching providers	Abu-Libdeh et al. (2010); Mastroeni and Naldi (2012); Ruiz-Alvarez and Humphrey (2011); 2012)
Cost of backsourcing or discarding	Martens et al. (2012)

increasing) and $b > -1$ (if the demand is positive at the beginning of the storage period) are real numbers.

Given the demand function above, the equation for z_{max} specified in Eq. (B.5) can be rewritten as

$$\frac{1}{u}e^{\frac{u-1}{u}a(w-z)} + \frac{u-1}{u}e^{-\frac{1}{u}az} = 1. \tag{B.13}$$

Observe that for $z = w/2$, the left part of the equation above simplifies to

$$\frac{1}{u}e^{-\frac{aw}{2u}}\left(e^{\frac{aw}{2}} + u - 1\right) > 1. \tag{B.14}$$

Thus, the left part of Eq. (B.13) in the region $(w/2, w)$ is monotonically decreasing from $\frac{1}{u}e^{-\frac{aw}{2u}}(e^{\frac{aw}{2}} + u - 1) > 1$ to $\frac{1}{u} + \frac{u-1}{u}\frac{s(w)}{s(z)} < 1$. Therefore, there exists a value of $z_{\max} \in (w/2, w)$, satisfying Eq. (B.13). □

B5. Proof of Lemma 3.4

Proof. Let us calculate the derivative of the cost difference function in Eq. (13) with respect to the utility premium u:

$$\frac{df}{du} = p_o \frac{az(w-z)}{u^2}. \tag{B.15}$$

Since $p_o > 0$, $a > 0$ and $0 < z < w$, it follows that the function is monotonically increasing. In addition, since the function f is positive for every $0 < z < w$, the cost savings are increasing as the utility premium increases. □

B6. Proof of Lemma 3.5

Proof. It can be easily seen that $f > 0$ iff

$$u\,p_o\left(\int_{\frac{u-1}{u}w}^{w} s(t)dt - \int_{\frac{u-1}{u}z}^{z} s(t)dt - \int_{z+\frac{u-1}{u}(w-z)}^{w} s(t)dt\right) > c_r. \tag{B.16}$$

The left part of the equation reflects the benefits achievable through the refinement of the reassessment interval, in line with Eq. (18). Thus, re-evaluating the storage needs more often reduces the overall hybrid storage cost if the cost benefits due to reassessment are higher than the cost of reassessment. □

References

Abu-Libdeh, H., Princehouse, L., Weatherspoon, H., 2010. RACS: a case for cloud storage diversity. In: Proceedings of the 1st ACM Symposium on Cloud Computing. ACM, pp. 229–240.

Adams, I.F., Long, D.D., Miller, E.L., Pasupathy, S., Storer, M.W., 2009. Maximizing efficiency by trading storage for computation. In: Proc. of the Workshop on Hot Topics in Cloud Computing.

Adelman, M.A., 1949. The large firm and its suppliers. Rev. Econ. Stat. 31 (2), pp.113–118.

Agarwala, S., Jadav, D., Bathen, L.A., 2011. iCostale: adaptive cost optimization for storage clouds. In: Cloud Computing (CLOUD), 2011 IEEE International Conference on. IEEE, pp. 436–443.

Altmann, J., Kashef, M.M., 2014. Cost model based service placement in federated hybrid clouds. Future Generation Computer Systems 41, 79–90.

André, F., Kermarrec, A.-M., Le Merrer, E., Le Scouarnec, N., Straub, G., van Kempen, A., 2014. Archiving cold data in warehouses with clustered network coding. In: Proceedings of the Ninth European Conference on Computer Systems. ACM, New York, NY, USA, pp. 21:1–21:14.

Andrikopoulos, V., Song, Z., Leymann, F., 2013. Supporting the migration of applications to the cloud through a decision support system. In: IEEE Sixth International Conference on Cloud Computing (CLOUD). IEEE, pp. 565–572.

Armbrust, M., Fox, A., Griffith, R., Joseph, A.D., Katz, R., Konwinski, A., Lee, G., Patterson, D., Rabkin, A., Stoica, I., Zaharia, M., 2010. A view of cloud computing. Commun. ACM 53, 50–58.

Babcock, C., 2010. Management Strategies for the Cloud Revolution: How Cloud Computing Is Transforming Business and Why You Can't Afford to Be Left Behind. McGraw-Hill Education.

Bacour, C., Jacquemoud, S., Tourbier, Y., Dechambre, M., Frangi, J.-P., 2002. Design and analysis of numerical experiments to compare four canopy reflectance models. Remote Sens. Environ. 79 (1), 72–83.

Beaty, K., Naik, V., Perng, C.S., 2011. Economics of cloud computing for enterprise it. IBM J. Res. Dev. 55 (6), 12:1–12:13. doi:10.1147/JRD.2011.2172254.

van Belle, G., 2008. Statistical Rules of Thumb. Wiley & Sons.

Bibi, S., Katsaros, D., Bozanis, P., 2012. Business application acquisition: on-premise or saas-based solutions? IEEE Software 29 (3), 86–93.

Bittencourt, L.F., Madeira, E.R.M., 2011. HCOC: a cost optimization algorithm for workflow scheduling in hybrid clouds. J. Internet Services Appl. 2 (3), 207–227.

Borthakur, D., 2007. The hadoop distributed file system: Architecture and design. The Apache Software Foundation. http://hadoop.apache.org/docs/r1.2.1/hdfs_design.pdf.

Bowman, K.P., Sacks, J., Chang, Y.-F., 1993. Design and analysis of numerical experiments. J. Atmos. Sci. 50 (9), 1267–1278.

Brumec, S., Vrček, N., 2013. Cost effectiveness of commercial computing clouds. Inf. Syst. 38 (4), 495–508.

Brydon, M., 2006. Evaluating strategic options using decision-theoretic planning. Inf. Technol. Manage. 7 (1), 35–49.

Cai, H., Wang, N., Zhou, M.J., 2010. A transparent approach of enabling saas multi-tenancy in the cloud. In: Proceedings of the 2010 6th World Congress on Services. IEEE Computer Society, pp. 40–47.

Calheiros, R.N., Ranjan, R., Beloglazov, A., De Rose, C.A., Buyya, R., 2011. Cloudsim: a toolkit for modeling and simulation of cloud computing environments and evaluation of resource provisioning algorithms. Software 41 (1), 23–50.

Carlton, D.W., 1979. Vertical integration in competitive markets under uncertainty. J. Ind. Econ. 27 (3), pp.189–209.

Celesti, A., Fazio, M., Villari, M., Puliafito, A., 2016. Adding long-term availability, obfuscation, and encryption to multi-cloud storage systems. J. Network Comput. Appl. 59, 208–218. http://dx.doi.org/10.1016/j.jnca.2014.09.021.

Cerviño, J., Rodríguez, P., Trajkovska, I., Escribano, F., Salvachúa, J., 2013. A cost-effective methodology applied to videoconference services over hybrid clouds. Mobile Networks Appl. 18 (1), 103–109.

Chen, P.-y., Wu, S.-y., 2013. The impact and implications of on-demand services on market structure. Inf. Syst. Res. 24 (3), 750–767.

Clements, A.T., Ahmad, I., Vilayannur, M., Li, J., et al., 2009. Decentralized deduplication in san cluster file systems.. In: USENIX Annual Technical Conference, pp. 101–114.

Colombo, S.P., Rizzo, C.L., 2009. Numerical Simulation Research Progress. Nova Science Publishers.

Dobre, D., Viotti, P., Vukolić, M., 2014. Hybris: robust hybrid cloud storage. In: Proceedings of the ACM Symposium on Cloud Computing. ACM, New York, NY, USA, pp. 12:1–12:14.

Fadel, A.S., Fayoumi, A.G., 2013. Cloud resource provisioning and bursting approaches. In: 14th ACIS International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD). IEEE, pp. 59–64.

Fan, C.-T., Wang, W.-J., Chang, Y.-S., 2011. Agent-based service migration framework in hybrid cloud. In: 13th International Conference on High Performance Computing and Communications (HPCC). IEEE, pp. 887–892.

Freytag, P.V., Kirk, L., 2003. Continuous strategic sourcing. J. Purchasing Supply Manage. 9 (3), 135–150.

Gauger, A., 2013. Amazon's 'mountain of margin' in cloud services: over 80% profit. VentureBeat news, available online at http://venturebeat.com/2013/09/05/amazons-mountain-of-margin-in-cloud-services-over-80-profit/(retrieved March 10, 2015).

Gonzalez, J., Perez, J.C., Sosa-Sosa, V., Rodriguez Cardoso, J.F., Marcelin-Jimenez, R., 2013. An approach for constructing private storage services as a unified fault-tolerant system. J. Syst. Software 86 (7), 1907–1922.

Greenberg, A., Hamilton, J., Maltz, D.A., Patel, P., 2008. The cost of a cloud: research problems in data center networks. SIGCOMM Comput. Commun. Rev. 39, 68–73.

Gregor, S., Hevner, A.R., 2013. Positioning and presenting design science research for maximum impact. MIS Quarterly 37 (2), 337–356.

Gregory, R.W., Beck, R., Keil, M., 2013. Control balancing in information systems development offshoring projects. MIS Quarterly 37 (4), 1211–1232.

Gulati, R., Lawrence, P.R., Puranam, P., 2005. Adaptation in vertical relationships: beyond incentive conflict. Strategic Manage. J. 26 (5), 415–440.

Hajjat, M., Sun, X., Sung, Y.-W.E., Maltz, D., Rao, S., Sripanidkulchai, K., Tawarmalani, M., 2010. Cloudward bound: planning for beneficial migration of enterprise applications to the cloud. ACM SIGCOMM Comput. Commun. Rev. 40 (4), 243–254.

Han, H., Lee, Y.C., Choi, S., Yeom, H.Y., Zomaya, A.Y., 2013. Cloud-aware processing of MapReduce-based OLAP applications. In: Proceedings of the Eleventh Australasian Symposium on Parallel and Distributed Computing-Volume 140. Australian Computer Society, Inc., pp. 31–38.

Han, Y., 2011. Cloud computing: case studies and total cost of ownership. Inf. Technol. Lib. 30 (4), 198–206.

Harrigan, K.R., 1986. Matching vertical integration strategies to competitive conditions. Strategic Manage. J. 7 (6), 535–555.

Heide, J.B., 2003. Plural governance in industrial purchasing. J. Marketing 67 (4), 18–29.

Heide, J.B., Kumar, A., Wathne, K.H., 2013. Concurrent sourcing, governance mechanisms, and performance outcomes in industrial value chains. Strategic Manage. J. 35 (8), 1164–1185.

Hernández, S., Fabra, J., Álvarez, P., Ezpeleta, J., 2013. Cost evaluation of migrating a computation intensive problem from clusters to cloud. In: Economics of Grids, Clouds, Systems, and Services. Springer, pp. 90–105.
Hevner, A.R., March, S.T., Park, J., Ram, S., 2004. Design science in information systems research. MIS Quarterly 28 (1), 75–105.
Hill, T., 1994. Manufacturing Strategy. Richard D. Irwin, Burr Ridge, IL.
Huang, K.-C., Shen, B.-J., 2015. Service deployment strategies for efficient execution of composite saas applications on cloud platform. J. Syst. Software 107, 127–141. http://dx.doi.org/10.1016/j.jss.2015.05.050.
Hunter, W.G., Hunter, J.S., George, E., 1978. Statistics for experimenters: an introduction to design, data analysis, and model building. Wiley New York.
IDC, 2014. The Digital Universe of Opportunities: Rich Data and the Increasing Value of the Internet of Things. EMC Digital Universe with Research & Analysis by IDC, Executive Summary. IDC. available from http://www.emc.com/leadership/digital-universe/2014iview/executive-summary.htm(retrieved March 10, 2015)
Jackson, J., 2014. Price war! Amazon cuts cloud costs to counter Google. IDG News Service, Computerworld, available from http://www.computerworld.com/article/2489105/cloud-computing/price-war--amazon-cuts-cloud-costs-to-counter-google.html, last retrieved on 30.9.2014.
Jacobides, M.G., Billinger, S., 2006. Designing the boundaries of the firm: From "make, buy, or ally" to the dynamic benefits of vertical architecture. Org. Sci. 17 (2), 249–261.
Jiekak, S., Kermarrec, A.-M., Le Scouarnec, N., Straub, G., Van Kempen, A., 2013. Regenerating codes: a system perspective. ACM SIGOPS Oper. Syst. Rev. 47 (2), 23–32.
Juan-Verdejo, A., Baars, H., 2013. Decision support for partially moving applications to the cloud: the example of business intelligence. In: Proceedings of the 2013 international workshop on Hot topics in cloud services. ACM, pp. 35–42.
Kabbedijk, J., Bezemer, C.-P., Jansen, S., Zaidman, A., 2015. Defining multi-tenancy: a systematic mapping study on the academic and the industrial perspective. J. Syst. Software 100, 139–148. http://dx.doi.org/10.1016/j.jss.2014.10.034.
Kashef, M.M., Altmann, J., 2012. A cost model for hybrid clouds. In: Economics of Grids, Clouds, Systems, and Services. Springer, pp. 46–60.
Khajeh-Hosseini, A., Greenwood, D., Smith, J.W., Sommerville, I., 2012. The cloud adoption toolkit: supporting cloud adoption decisions in the enterprise. Software 42 (4), 447–465.
Khajeh-Hosseini, A., Sommerville, I., Bogaerts, J., Teregowda, P., 2011. Decision support tools for cloud migration in the enterprise. In: IEEE International Conference on Cloud Computing (CLOUD). IEEE, pp. 541–548.
Klein, A., 2014. Storage pod 4.0: direct wire drives – faster, simpler and less expensive. Backblaze blog, available from https://www.backblaze.com/blog/backblaze-storage-pod-4/, last retrieved on 29.9.2014.
Klems, M., Nimis, J., Tai, S., 2009. Do clouds compute? a framework for estimating the value of cloud computing. In: Designing E-Business Systems. Markets, Services, and Networks. Springer, pp. 110–123.
Kondo, D., Javadi, B., Malecot, P., Cappello, F., Anderson, D.P., 2009. Cost-benefit analysis of cloud computing versus desktop grids. In: Parallel & Distributed Processing, 2009. IPDPS 2009. IEEE International Symposium on. IEEE, pp. 1–12.
Koomey, J., Brill, K., Turner, P., Stanley, J., Taylor, B., 2007. A simple model for determining true total cost of ownership for data centers. Uptime Institute White Paper, Version 2.
Kotlarsky, J., Scarbrough, H., Oshri, I., 2014. Coordinating expertise across knowledge boundaries in offshore-outsourcing projects: the role of codification. MIS Quarterly 38 (2), 607–627.
Kratzke, N., 2012. Cloud computing costs and benefits. In: Cloud Computing and Services Science. Springer, pp. 185–203.
Krzeminska, A., Hoetker, G., Mellewigt, T., 2013. Reconceptualizing plural sourcing. Strategic Manage. J. 34 (13), 1614–1627.
Laatikainen, G., Mazhelis, O., Tyrväinen, P., 2014. Role of acquisition intervals in private and public cloud storage costs. Decis. Support Syst. 57, 320–330.
Lacity, M., Khan, S., Willcocks, L., 2009. A review of the it outsourcing literature: insights for practice. J. Strategic Inf. Syst. 18 (3), 130–146.
Lacity, M.C., Solomon, S., Yan, A., Willcocks, L.P., 2011. Business process outsourcing studies: a critical review and research directions. J. Inf. Technol. 26 (4), 221–258.
Leong, L., Toombs, D., Gill, B., Petri, G., Haynes, T., 2014. Magic Quadrant for Cloud Infrastructure as a Service. Technical Report. Gartner.
Lima, D., Moura, B., Oliveira, G., Ribeiro, E., Araujo, A., Holanda, M., Togawa, R., Walter, M., 2014. A storage policy for a hybrid federated cloud platform: a case study for bioinformatics. In: Cluster, Cloud and Grid Computing (CCGrid), 2014 14th IEEE/ACM International Symposium on, pp. 738–747.
Long, S., Zhao, Y., Chen, W., 2014. A three-phase energy-saving strategy for cloud storage systems. J. Syst. Software 87, 38–47. http://dx.doi.org/10.1016/j.jss.2013.08.018.
Malawski, M., Figiela, K., Nabrzyski, J., 2013. Cost minimization for computational applications on hybrid cloud infrastructures. Future Gener. Comput. Syst. 29 (7), 1786–1794.
Mao, B., Jiang, H., Wu, S., Fu, Y., Tian, L., 2014. Read-performance optimization for deduplication-based storage systems in the cloud. ACM Trans. Storage (TOS) 10 (2), 6.
Martens, B., Teuteberg, F., 2012. Decision-making in cloud computing environments: a cost and risk based approach. Inf. Syst. Frontiers 14 (4), 871–893.
Martens, B., Walterbusch, M., Teuteberg, F., 2012. Costing of cloud computing services: a total cost of ownership approach. In: 45th Hawaii International Conference on System Science (HICSS). IEEE, pp. 1563–1572.
Mastroeni, L., Naldi, M., 2011. Long-range evaluation of risk in the migration to cloud storage. In: IEEE 13th Conference on Commerce and Enterprise Computing (CEC), pp. 260–266. doi:10.1109/CEC.2011.47.
Mastroeni, L., Naldi, M., 2012. Pricing of insurance policies against cloud storage price rises. ACM SIGMETRICS Perform. Eval. Rev. 40 (2), 42–45.
Mazhelis, O., 2012. Costs of using hybrid cloud infrastructure: towards a general framework. In: Software Business. Springer, pp. 261–266.
Mazhelis, O., Fazekas, G., Tyrvainen, P., 2012. Impact of storage acquisition intervals on the cost-efficiency of the private vs. public storage. In: 5th International Conference on Cloud Computing (CLOUD). IEEE, pp. 646–653.
Mazhelis, O., Tyrväinen, P., 2011. Role of data communications in hybrid cloud costs. In: Proceedings of the 37th EUROMICRO Conference on Software Engineering and Advanced Applications.
Mazhelis, O., Tyrväinen, P., 2012. Economic aspects of hybrid cloud infrastructure: User organization perspective. Inf. Syst. Frontiers 14 (4), 845–869.
Mazhelis, O., Tyrväinen, P., Tan, K.E., Hiltunen, J., 2012. Assessing cloud infrastructure costs in communications-intensive applications. In: Cloud Computing and Services Science. Springer, pp. 277–293.
McClure, T., 2014. Hybrid model offers more secure file sync and share. Storage Mag. 13 (1), 28–30.
Mell, P., Grance, T., 2011. The NIST Definition of Cloud Computing. Special Publication 800-145. National Institute of Standards and Technology. available from http://www.csrc.nist.gov/groups/SNS/cloud-computing/
Mian, R., Martin, P., Zulkernine, F., Vazquez-Poletti, J.L., 2012. Estimating resource costs of data-intensive workloads in public clouds. In: Proceedings of the 10th International Workshop on Middleware for Grids, Clouds and e-Science. ACM, New York, NY, USA, pp. 3:1–3:6.
Misra, S.C., Mondal, A., 2011. Identification of a company's suitability for the adoption of cloud computing and modelling its corresponding return on investment. Math. Comput. Modell. 53 (3), 504–521.
Mols, N.P., 2010. Economic explanations for concurrent sourcing. J. Purchasing Supply Manage. 16 (1), 61–69.
Mols, N.P., Hansen, J.R., Villadsen, A.R., 2012. Plural governance: the effect of internal production on supplier performance. Ind. Marketing Manage. 41 (5), 874–885.
Muniswamy-Reddy, K.-K., Seltzer, M., 2010. Provenance as first class cloud data. ACM SIGOPS Oper. Syst. Rev. 43 (4), 11–16.
Nufire, T., 2011. Petabytes on a budget v2.0: revealing more secrets. Backblaze blog, available from http://blog.backblaze.com/2011/07/20/petabytes-on-a-budget-v2-0revealing-more-secrets/, last retrieved on 29.9.2014.
Opitz, A., König, H., Szamlewska, S., 2008. What does grid computing cost? J. Grid Comput. 6 (4), 385–397.
Palankar, M.R., Iamnitchi, A., Ripeanu, M., Garfinkel, S., 2008. Amazon s3 for science grids: a viable solution? In: Proceedings of the 2008 international workshop on Data-aware distributed computing. ACM, pp. 55–64.
Parmigiani, A., 2003. Concurrent sourcing: when do firms both make and buy?. Duke University.
Parmigiani, A., 2007. Why do firms both make and buy? an investigation of concurrent sourcing. Strategic Manage. J. 28 (3), 285–311.
Parmigiani, A., Mitchell, W., 2009. Complementarity, capabilities, and the boundaries of the firm: the impact of within-firm and interfirm expertise on concurrent sourcing of complementary components. Strategic Manage. J. 30 (10), 1065–1091.
Peffers, K., Tuunanen, T., Rothenberger, M., Chatterjee, S., 2007. A design science research methodology for information systems research. J. Manage. Inf. Syst. 24 (3), 45–77.
Porter, M., 1980. Competitive Strategy: Techniques for Analyzing Industries and Competitors. Free Press, New York.
Puranam, P., Gulati, R., Bhattacharya, S., 2013. How much to make and how much to buy? an analysis of optimal plural sourcing strategies. Strategic Manage. J. 34 (10), 1145–1161.
Reine, D., Kahn, M., 2013. Revisiting the search for long-term storage – a TCO analysis of tape and disk. The Clipper Group Calulator bulletin, available from http://www.clipper.com/Clipper_Tutorials_Index.htm, last retrieved on 29.9.2014.
RightScale, 2014. Rightscale 2014 state of the cloud report. Available online at http://www.rightscale.com/lp/2014-state-of-the-cloud-report, last retrieved on 29.9.2014.
Risch, M., Altmann, J., 2008. Cost analysis of current grids and its implications for future grid markets. In: Altmann, J., Neumann, D., T., F. (Eds.), Proceedings of the 5th international workshop on Grid Economics and Business Models. Springer-Verlag, Berlin, Heidelberg, pp. 13–27.
Ruiz-Alvarez, A., Humphrey, M., 2011. An automated approach to cloud storage service selection. In: Proceedings of the 2nd international workshop on Scientific cloud computing. ACM, pp. 39–48.
Ruiz-Alvarez, A., Humphrey, M., 2012. A model and decision procedure for data storage in cloud computing. In: The 12th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid). IEEE, pp. 572–579.
Sako, M., Chondrakis, G., M. Vaaler, P., 2013. How do firms balance making and buying? the case of legal services sourcing by fortune 500 companies. Forth-Coming. Available from https://test-intranet.law.ox.ac.uk/ckfinder/userfiles/files/Paper%20-%20Sako%20Chondrakis%20Vaaler(1).pdf, retrived on 8.8.2014
Sanchez, R., 1995. Strategic flexibility in product competition. Strategic Manage. J. 16 (S1), 135–159.
Sanchez, R., 2004. Understanding competence-based management: identifying and managing five modes of competence. J. Bus. Res. 57 (5), 518–532.

Schlagwein, D., Thorogood, A., Willcocks, L.P., 2014. How commonwealth bank of australia gained benefits using a standards- based, multi-provider cloud model. MIS Quarterly Executive 13 (4), 209–222.
Shifrin, M., Atar, R., Cidon, I., 2013. Optimal scheduling in the hybrid-cloud. In: IFIP/IEEE International Symposium on Integrated Network Management (IM 2013). IEEE, pp. 51–59.
Silva, L.A.B., Costa, C., Oliveira, J.L., 2013. A common {API} for delivering services over multi-vendor cloud resources. J. Syst. Software 86 (9), 2309–2317. http://dx.doi.org/10.1016/j.jss.2013.04.037.
Smith, J.E., Nair, R., 2005. The architecture of virtual machines. Computer 38 (5), 32–38.
Son, I., Lee, D., Lee, J.-N., Chang, Y.B., 2014. Market perception on cloud computing initiatives in organizations: an extended resource-based view. Inf. Manage. 51 (6), 653–669. http://dx.doi.org/10.1016/j.im.2014.05.006.
Sun, K., Li, Y., 2013. Effort estimation in cloud migration process. In: Service Oriented System Engineering (SOSE), 2013 IEEE 7th International Symposium on. IEEE, pp. 84–91.
Sun, Y., White, J., Eade, S., Schmidt, D.C., 2015. Roar: a qos-oriented modeling framework for automated cloud resource allocation and optimization http://dx.doi.org/10.1016/j.jss.2015.08.006.
Tak, B.C., Urgaonkar, B., Sivasubramaniam, A., 2011. To move or not to move: the economics of cloud computing. In: Proceedings of the 3rd USENIX conference on Hot topics in cloud computing. USENIX Association, p. 5.
Tak, B.C., Urgaonkar, B., Sivasubramaniam, A., 2013. Cloudy with a chance of cost savings. IEEE Trans. Parallel Distrib. Syst. 24 (6), 1223–1233.
Trummer, I., Leymann, F., Mietzner, R., Binder, W., 2010. Cost-optimal outsourcing of applications into the clouds. In: The Second International Conference on Cloud Computing Technology and Science (CloudCom), pp. 135–142. doi:10.1109/CloudCom.2010.64.
Truong, H.-L., Dustdar, S., 2010. Composable cost estimation and monitoring for computational applications in cloud computing environments. Procedia Comput. Sci. 1 (1), 2175–2184.
Turner, W. P., Seader, J. H., 2006. Dollars per kW plus dollars per square foot are a better datacenter cost model than dollars per square foot alone. The Uptime Institute White Paper.
TwinStrata, 2013. A snapshot into cloud storage adoption. TwinStrata White Paper.
Venters, W., Whitley, E.A., 2012. A critical review of cloud computing: researching desires and realities. JIT 27 (3), 179–197.
Villari, M., Celesti, A., Fazio, M., Puliafito, A., 2014. Evaluating a file fragmentation system for multi-provider cloud storage. Scalable Comput. 14 (4), 265–277.
Villari, M., Celesti, A., Tusa, F., Puliafito, A., 2013. Advances in Service-Oriented and Cloud Computing: Workshops of ESOCC 2013, Málaga, Spain, September 11-13, 2013, Revised Selected Papers. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 83–93.
Wagner, S.M., Bode, C., 2006. An empirical investigation into supply chain vulnerability. J. Purchasing Supply Manage. 12 (6), 301–312.
Walker, E., Brisken, W., Romney, J., 2010. To lease or not to lease from storage clouds. Computer 43, 44–50.
Walterbusch, M., Martens, B., Teuteberg, F., 2013. Evaluating cloud computing services from a total cost of ownership perspective. Manage. Res. Rev. 36 (6), 613–638.
Wang, W.-J., Chang, Y.-S., Lo, W.-T., Lee, Y.-K., 2013. Adaptive scheduling for parallel tasks with qos satisfaction for hybrid cloud environments. J. Supercomput. 66 (2), 783–811.
Wang, W.-J., Lo, Y.-M., Chen, S.-J., Chang, Y.-S., 2012. Intelligent application migration within a self-provisioned hybrid cloud environment. In: Computer Science and Convergence. Springer, pp. 295–303.
van de Water, H., van Peet, H.P., 2006. A decision support model based on the analytic hierarchy process for the make or buy decision in manufacturing. J. Purchasing Supply Manage. 12 (5), 258–271.
Weddle, C., Oldham, M., Qian, J., Wang, A.-I.A., Reiher, P., Kuenning, G., 2007. Paraid: a gear-shifting power-aware raid. Trans. Storage 3 (3). doi:10.1145/1289720.1289721.
Weigelt, C., Sarkar, M., 2012. Performance implications of outsourcing for technological innovations: managing the efficiency and adaptability trade-off. Strategic Manage. J. 33 (2), 189–216.
Weinhardt, C., Anandasivam, A., Blau, B., Borissov, N., Meinl, T., Michalk, W., Stößer, J., 2009. Cloud computing–a classification, business models, and research directions. Bus. Inf. Syst. Eng. 1 (5), 391–399.
Weinman, J., 2011. Cloudonomics: a rigorous approach to cloud benefit quantification. J. Software Technol. 14, 10–18.
Weinman, J., 2011b. Mathematical proof of the inevitability of cloud computing. Working paper, available from http://www.joeweinman.com (last retrieved on February 28, 2012).
Weinman, J., 2011c. Time is money: The value of “on-demand”. Working paper, available from http://www.joeweinman.com (last retrieved on February 28, 2012).
Weinman, J., 2012. Cloudonomics: The Business Value of Cloud Computing. John Wiley & Sons.
Willcocks, L., Lacity, M., 2012. The New IT Outsourcing Landscape: From Innovation to Cloud Services. Palgrave Macmillan.
Williamson, O., 1985. The Economic Institutions of Capitalism. The Free Press, New York.
Winsberg, E., 2003. Simulated experiments: methodology for a virtual world. Philos. Sci. 70 (1), 105–125.
Xie, T., 2008. Sea: a striping-based energy-aware strategy for data placement in raid-structured storage systems. IEEE Trans. Comput. 57 (6), 748–761. doi:10.1109/TC.2008.27. Cited By 49
Yuan, D., Yang, Y., Liu, X., Chen, J., 2010. A cost-effective strategy for intermediate data storage in scientific cloud workflow systems. In: Parallel & Distributed Processing (IPDPS), 2010 IEEE International Symposium on. IEEE, pp. 1–12.
Yuan, D., Yang, Y., Liu, X., Chen, J., 2011. On-demand minimum cost benchmarking for intermediate dataset storage in scientific cloud workflow systems. J. Parallel Distrib. Comput. 71 (2), 316–332.
Yuan, D., Yang, Y., Liu, X., Zhang, G., Chen, J., 2010. A data dependency based strategy for intermediate data storage in scientific cloud workflow systems. Concurrency Comput. 24 (9), 956–976.
Zhang, H., Li, P., Zhou, Z., Wu, J., Yu, X., 2014. A privacy-aware virtual machine migration framework on hybrid clouds. J. Netw. 9 (5), 1086–1095.
Zhu, Q., Chen, Z., Tan, L., Zhou, Y., Keeton, K., Wilkes, J., 2005. Hibernator: helping disk arrays sleep through the winter. SIGOPS Oper. Syst. Rev. 39 (5), 177–190. doi:10.1145/1095809.1095828.
Zhu, Y., Hu, H., Ahn, G.-J., Yau, S.S., 2012. Efficient audit service outsourcing for data integrity in clouds. J. Syst. Software 85 (5), 1083–1095. http://dx.doi.org/10.1016/j.jss.2011.12.024.

Gabriella Laatikainen is a PhD student at the Department of Computer Science and Information Systems, University of Jyväskylä, Finland. She received a degree of MSc. Mathematics and Computer Science from University of Debrecen, Hungary in 2007. Her research interests include cloud services, software pricing, business models in IT services industry.

Oleksiy Mazhelis is a post-doc researcher at the Agora Center, University of Jyväskylä, Finland. He received a degree of MSc (Specialist) from Kharkov National University of Radio-Electronics, Ukraine in 1997, and received his licentiate and doctoral degrees from the University of Jyväskylä in 2004 and 2007, respectively. Starting from 2004, he was working in various research projects conducted in collaboration with industrial partners. His current research interests encompass techno-economics, systems analysis, machine learning, and pattern recognition, applied to the domains of software industry evolution, internet-of-things, telecommunications and cloud software, as well as intelligent transportation systems.

Pasi Tyrvainen is Professor of Information Systems and Director of Agora Center at the University of Jyväskylä. He received his doctoral degree at Helsinki University of Technology in 1994 and is a member of IEEE, ACM and AoM. His previous affiliations include R&D management positions at Honeywell Industrial Control and Nokia Research Center. His research interests include enterprise content management, cloud services and software business, and studies in these areas laid the ground for establishing the ICSOB conference series on software business research in 2010. On these subjects he has written several books and published numerous articles both in business and engineering management journals.