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Decision-making in cloud computing environments: A cost and risk based approach

Benedikt Martens · Frank Teuteberg

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Abstract In this article a sophisticated formal mathematical decision model is developed that supports the selection of Cloud Computing services in a multisourcing scenario. The objective is to determine the selection of appropriate Cloud Computing services offered by different providers. In order to do so, we consider cost as well as risk factors which are relevant to the decision scope. For example, coordination costs, IT service costs, maintenance costs and the costs of taken risks were compared. Risks are modeled by means of the three common security objectives integrity, confidentiality and availability. The managerial implications of the model lie in the sustainable decision support and the comprehensive decision approach. The formal model is prototypically implemented using a software tool and examined with the help of a simulation study in three realistic scenarios and a sensitivity analysis.

Keywords Cloud computing · Decision model · Risk management · IT outsourcing · Simulation study

1 The need for cost and risk management in cloud computing

During the last years, Cloud Computing has been a hot topic for market analysts and companies and is expected to reach maturity within the next 4 to 6 years (Pring et al. 2009). The initial enthusiasm has given way to a critical evaluation of the benefits that companies can draw from Cloud Computing services. In this context, aspects of hidden cost factors, risk and security issues seem to be of particularly high interest (Weinhardt et al. 2009; Armbrust et al. 2010). Cloud Computing literature has generally acknowledged the fact that new types of risks are on the rise. Especially early adopters are facing a higher number of risks in connection with new Cloud Computing services (Lacity et al. 2009; Martens and Teuteberg 2009). For instance, the classic lock-in effect (economic risk factor) which has been widely discussed with reference to IT outsourcing needs to be considered for Cloud Computing as well (Leimeister et al. 2010). Technical aspects, as e. g. insecure multi-tenant IT architectures, hold new risk factors and therefore need to be evaluated with care. Thus, before sourcing Cloud Computing services companies should prepare by using decision-making tools that account for both cost and risk factors. As we show during the model development and evaluation, decision makers will be overwhelmed by such huge amounts of data that are necessary to decide for the most adequate Cloud Computing service.

In this article we introduce a sophisticated formal mathematical model for decision-making in Cloud Computing that takes a perspective on cost and risk factors. The model is built on a solid theoretical basis (transaction cost theory, production costs theory, resource based view, agency theory, learning theory and relationship theory) and, in its original form, followed the cooperative sourcing model created by Beimborn (2008). Because of the multisourcing strategy that is frequently applied both in IT outsourcing and Cloud Computing (Levina and Su 2008) the model makes it possible to divide a Cloud Computing service request into subservices which can then be procured from

B. Martens (✉) · F. Teuteberg
Department of Economics and Business Administration,
Accounting and Information Systems, University of Osnabrueck,
Katharinenstraße 1,
49069 Osnabrück, Germany
e-mail: benedikt.martens@uni-osnabrueck.de
URL: http://www.uwi.uni-osnabrueck.de

F. Teuteberg
e-mail: frank.teuteberg@uni-osnabrueck.de
URL: http://www.uwi.uni-osnabrueck.de

several different providers. The model makes a basic distinction between a cost-oriented (Cloud Computing service, negotiation, allocation, coordination, adoption, maintenance and agency costs) and a risk-oriented perspective (confidentiality, integrity and availability). We explore the model with the help of a simulation study that is based on features of existing Cloud Computing offerings and on company data. The robustness of the decision calculus is tested by means of a sensitivity analysis.

Different research fields adopt different definitions of risk, depending on their particular research objects (Aubert et al. 2005). In finance, for instance, risk is defined as exogenous and as variance of a decision outcome, since the decision maker has no influence on the risk outcome (Jurison 1995). In contrast, management theory assumes the loss probability and the volume of loss to be known prior to decision-making. In our work we follow Aubert et al. (2005) in defining risk as the product of the probability of a negative outcome and the importance of loss caused by the occurrence of this outcome. Furthermore, our approach to risk is based on insights from agency and transaction cost theory.

The paper is structured as follows: Section 2 points to the research gap on risk management and formal mathematical models in Cloud Computing and IT outsourcing respectively, which is identified by means of a systematic literature review. Subsequently, the theoretical foundation of the model is outlined. Section 3 discusses the chosen research method and the objective of the model. In Section 4 the actual model is described in detail and simulated and analyzed in Section 5 with three different scenarios and a sensitivity analysis. Finally, implications, limitations and future research are outlined in Section 6.

2 Related work and theoretical background

2.1 Cloud computing as an IT outsourcing model

A common definition of the concept of Cloud Computing has not yet been established in scientific literature (Weinhardt et al. 2009). By means of a literature review, Leimeister et al. (2010) have found out that Cloud Computing is mainly described as an IT outsourcing model for the on-demand, online delivery of scalable IT services on the basis of virtualization technology and pay-per-use pricing models. In this context, the term 'cloud' refers to data centers that offer virtualized computer resources and services (Armbrust et al. 2010). The three main types of Cloud Computing services are: Software as a Service (SaaS), which refers to application services; Platform as a Service (PaaS), i.e. developer platforms; and Infrastructure as a Service (IaaS), which mainly denotes storage services and computing power services (Weinhardt et al. 2009). Cloud Computing services are often highly substitutable and SaaS in particular shares many common features with Application Service Providing (ASP) (Brodsky and Tan 2003). Users of Cloud Computing services benefit from savings gained through lower capital and implementation costs (Singh et al. 2004). On the other hand, 'outsourcing' generally applies to the transfer of business units/functions to external service providers. Therefore, the term is not necessarily technology-based (Dibbern et al. 2004). However, in IT outsourcing the transfer process is limited to the realm of IT, where it can take on various different forms. It may refer to the hiring of an external software developer or to the delegation of the management of complete data processing centers to external service providers (Brodsky and Tan 2003). In summary, IT outsourcing can be regarded as a make-or-buy-decision as part of IT management. In Table 1 we compare the characteristics of Cloud Computing and IT Outsourcing and cite important references.

Cloud Computing and classic IT outsourcing share the same basic functions and provide similar benefits to their users (Levina and Su 2008; Leimeister et al. 2010). However, many limitations of traditional IT outsourcing do not apply to the concept of Cloud Computing, which better meets the increasing demand for more efficiency, (monetary) flexibility and innovation (Talukder et al. 2010). In summary, the Cloud Computing paradigm can be regarded as an IT outsourcing model that unites different features of infrastructure and application services (Leimeister et al. 2010). Thus, methods and (decision) models developed for IT outsourcing are also applicable (though in a modified way) to the management of Cloud Computing services. Also, existing literature on IT outsourcing provides a solid basis for future research on Cloud Computing.

2.2 Analysis of mathematical models in IT outsourcing

2.2.1 Search process

We based our literature analysis on two systematic literature reviews about IT outsourcing: Dibbern et al. (2004), time horizon from 1988 to 2002; Martens and Teuteberg (2009), time horizon from 2002 to 2008. To fill the gap until 2010 we extended the scope of the review by Martens and Teuteberg (2009) to articles dating from 2008 to September 2010. The focus of our systematic literature review is the identification of analytical (mathematical) models with a focus on decision-making in Cloud Computing and IT outsourcing. We followed the proven course of action of vom Brocke et al. (2009) and relied on the journal ranking list published by WKWI in 2008 with 23 high quality information systems journals. Since this ranking has a strong focus on the German information system research,

Table 1 Characteristics of Cloud Computing and IT outsourcing

Characteristic	IT outsourcing	Cloud Computing
Negotiation	Pricing models, payment structures and SLAs can be completely negotiated by the user company (Levina and Ross 2003).	Large providers solely offer standardized SLAs with little possibilities for negotiation and customization (Martens et al. 2011).
Location of the Servers (Hardware)	Servers are located in-house or in the data center of the provider (Dibbern et al. 2004).	Hardware resources are solely located in third-party data centers (Weinhardt et al. 2009).
Architecture and Resource Management	One physical server is determined for one particular client (Lacity and Willcocks 2003).	Multi-tenant architecture to realize economies of scale (Huang and Wang 2009).
Pricing Model	Licensing fee or pricing scheme like consulting services (low pricing transparency); resources are not divisible (Poston et al. 2009).	Detailed price discrimination on an usage-depend basis (e. g. per gigabyte or to-the-minute billing) (Lehmann and Buxmann 2009).
Degree of Automation	Low Degree of Automation: manual scaling of required resources (Tan and Sia 2006).	High Degree of Automation: automatic scaling of required resources (Buyya et al. 2009).
Standardization of IT Services	Individual development, implementation and/or management of IT services (Lacity and Willcocks 2003).	Highly substitutable and standardized Cloud Computing services (Bardhan et al. 2010).
Legal Responsibility	The user company is responsible for the data protection and the legal effects (Govindarajan and Lakshmanan 2010).	

we extended it by adding the top 16.8% (21 of 125 Journals) of all journals included in the AIS ranking list. That approach result in a selection of 32 journals. As a further step, a keyword search for "cloud computing" and "outsourcing" was applied to the search engine of each journal. To extend the literature basis we conducted a forward and backward search and searched in publisher independent journal data bases like EBSCO (Business Source Complete, EconLit (full text)) or Science Direct. We included as well doctoral theses, which we identified within this process.

We found several articles that applied a formal mathematical approach, but concentrate on topics like pricing methods in Cloud Computing from a provider perspective (e. g. Püschel et al. 2009) or present economic models (e. g. Cha et al. 2008). We omitted these papers to focus exclusively on formal decision models. Further, papers with a focus on risk management do not often apply a formal mathematical approach. We received an overall number of 10 references.

2.2.2 Literature analysis

The identified articles are summarized in Table 2 and are characterized according to the following criteria, which support the identification of a research gap on the topic of formal mathematical models in Cloud Computing:

- Content: Which topics/contents are covered?
- Formalization of Costs and Risks: Which cost and risk factors are considered?
- Evaluation: Do the authors present an evaluation approach and, if so, which kind of evaluation?
- Applied Theory: Does the paper apply a specific theory?

Our literature review has revealed several critical aspects of existing formal mathematical decision models. Many researchers tend to formalize specific aspects of IT outsourcing and Cloud Computing instead of trying to take a comprehensive perspective that captures the complexity of reality. For instance, coordination costs (Cheng et al. 2006), task interdependencies (Knolmayer 1997; Cheng et al. 2006) or risk management (Gupta et al. 2008; Lammers 2004) are discussed in different (isolated) models. Furthermore, most of them take an either exclusively cost-oriented (Braunwarth and Heinrich 2008; Chaudhury et al. 1995) or (more rarely) a strictly risk-oriented perspective (Gupta et al. 2008). In this context the doctoral thesis of Beimborn (2008) constitutes a notable exception, for the author takes a comprehensive view on multi cost factors on the basis of a multi theoretical perspective. As a general rule, cost-theoretical models tend to oversimplify matters of risk and vice versa. For instance, the cost-theoretical model by Lammers (2004) only covers risk by means of a risk-adjusted discount rate instead of modeling the specific risk factors that have an impact on the decision environment. On the other hand, in most risk-oriented approaches costs only occur in the form of a few roughly defined variables (cf. Gupta et al. 2008).

The articles presented in Table 2 confirm the view of Dibbern et al. (2004) who posit that many researchers choose to ignore the principles of empirical and conceptual research and thus design models on the basis of non-validated criteria. Furthermore, our research results verify the observation of Martens and Teuteberg (2009) and Schniederjans and Zuckweiler (2004) that risk management is not adequately considered in the field of IT outsourcing and Cloud Computing. In particular, we found that it is rarely accounted for in formal models. It also became

Table 2 Articles on formal mathematical IT outsourcing decision approaches

Reference	Content	Cost formalization	Risk formalization	Evaluation approach	Applied theory
(Kauffman and Sougstad 2008)	Analytic model and decision support approach focusing on ex-ante contract evaluation, SLAs and negotiation.	IT service costs are modeled as a stochastic Gauss-Wiener process	generic risk modeling with the profit-at-risk approach	Simulation	Profit at Risk Approach (contract profitability vs. service level risk)
(Braunwarth and Heinrich 2008)	Analytic model for the selection of IT services based on interoperability standards and cost and risk factors.	switching costs, integration costs, learning effects	risk of service failure	fictitious Case Study	Portfolio Theory
(Singh et al. 2004)	Software rental agreements: ASP decision support tool is modeled as an IT investment decision.	cost comparison; in aggregated form only	uncertainty in rental software contracts	fictitious Case Study	Options Pricing Theory
(Lammers 2004)	Formal IT outsourcing decision model on making, buying or sharing an activity.	setup costs, transaction costs, governance costs	risk adjusted discount rate	no evaluation	Transaction Cost Theory and Resource based View
(Chaudhury et al. 1995)	Mixed integer programming model for multiple vendor selection scenarios.	no cost factors defined	uncertainty about the cost structure of the opponent	fictitious Case Study	Game Theory, Incentive Theory
(Beimborn 2008)	Development of a formal model of cooperative sourcing in the banking industry.	comprehensive modeling of cost factors like adoption, coordination, interface, and process costs e. g.	compliance risk	Simulation and Case Studies	Multi theory approach considering 9 different theories.
(Knolmayer 1997)	Mixed integer programming model for decision-making on single- or multi-sourcing and development of a three-level hierarchical planning approach.	coordination costs	n/a	Simulation	Organizational Theory
(Cheng et al. 2006)	Mixed integer programming model for decision-making on outsourcing addressing inter-related tasks and vendor performance.	coordination costs	n/a	fictitious Case Study is solved with optimizer	Transaction Cost Theory
(Wang et al. 2008)	Decision process applying an AHP and ELECTRE III approach. Considered factors: strategy, economic, risk, environment and quality factors.	generic formalization	generic formalization	Case Study	No theory applied.
(Gupta et al. 2008)	Quantitative framework for assessing the security of internet technology components.	n/a	threat indices and security components	Case Study	No theory applied.

obvious that only few models account for the risk attitude of the decision maker (Kauffman and Sougstad 2008; Braunwarth and Heinrich 2008). Often, a risk-neutral approach is chosen instead (Singh et al. 2004; Lammers 2004), which, however, does not correspond to reality.

In summary, we did not find a quantitative approach to decision-making that represents the special characteristics of Cloud Computing services, as e. g. multisourcing, service splitting or the particular pricing characteristics. Accordingly, our model aims at a balanced consideration of both cost and risk factors while incorporating the risk attitude of decision makers regarding IT services from the cloud.

2.3 Theories applied

In order to build our formal model on a solid theoretical basis, we drew on several existing theories, which are briefly outlined in Table 3. The table also illustrates which theories we adapted for which submodel (e. g. transaction cost theory for coordination costs) and contains examples for seminal work as well as related literature.

From a transaction cost theory perspective, every IT sourcing decision is based on a cost comparison of internal and external IT service procurement (Beimborn 2008). More precisely, the transaction costs caused by IT outsourcing need to be measured against the closely linked production costs caused by internally procured services (Williamson 1981). Resource-based theory begins where transaction cost theory ends, starting from the assumption that different companies also have different resources and capabilities at their disposal (Wernerfelt 1984). Dibbern (2004) explicitly mentions the inclusion of the parameters strategic and operational contribution of an IT service as a distinguishing feature between transaction cost theory and the resource-based view. The central idea in agency theory is the notion of information asymmetry resulting in goal incongruence between an agent (the external provider) and a principal (the user company) (Jensen and Meckling 1976). Choudhury and Sabherwal (2003) have found out that goal incongruence occurs particularly often in the field of IT outsourcing. Empirical studies in companies have revealed recognizable learning effects regarding IT outsourcing (Cha et al. 2008). The most important conclusion to be drawn from these studies is that a company's knowledge base increases along with its cumulative output. Finally, our model draws on basic elements of relationship theory like the exchange of services and money, monitoring and investment decisions. Relationship theory puts a focus on business culture, which, however, encompasses many aspects as e. g. the influence of decisions on other employees, sharing of material and non-material resources and corporate feeling (Kern 1997). These issues are indirectly incorporated into the model via the formalization of coordination costs, which, for example, are likely to rise if a decision finds little acceptance among employees (Dibbern 2004).

Table 3 Theories applied in our model

Theory	Description	Included in submodel	Seminal work (e. g.)	Applied in (e. g.)
Transaction cost theory	Cost comparison between external and internal procurement of services; consideration of production costs	Coordination, Maintenance, Agency, Negotiation, Adoption, Allocation and IT Service Costs	(Williamson 1981)	(Beimborn 2008; Dibbern 2004; Benlian et al. 2009; Chou and Chou 2007; Xin and Levina 2008)
Production cost theory	Costs (of all input factors) for performing the actual activities needed to complete a task (output, IT service)	IT Service, Coordination, Maintenance and Agency Costs	(Albach 1981)	(Beimborn 2008; Xin and Levina 2008)
Resource based view	Companies differ in their resources and capabilities as well as in terms of input and output factors	Allocation and Maintenance Costs, Confidentiality, Integrity and Availability Loss	(Wernerfelt 1984)	(Lammers 2004; Xin and Levina 2008)
Agency theory	Information asymmetry between provider and user company	Agency Costs, Confidentiality Loss, Integrity Loss	(Jensen and Meckling 1976)	(Tiwana and Bush 2007; Aubert et al. 2005; Bardhan et al. 2010)
Learning theory	Learning effect: cumulative output (number of outsourcing projects) is positively correlated with knowledge and experience levels and negatively correlated with execution costs	Negotiation Costs, Confidentiality, Integrity and Availability Loss	(Argote et al. 1990)	(Cha et al. 2008)
Relationship theory	Focus on buyer-supplier relationship: exchange of services and money, monitoring, investments and cultural aspects	Coordination Costs, Agency Costs, Confidentiality Loss	(Kern 1997)	(Lacity and Willcocks 2003; Bardhan et al. 2010)

3 Preliminary considerations

3.1 Requirements analysis and research process

Throughout the research process, we consulted multiple sources of data for the development of a valid model. For example, the requirements analysis in this section is based on the identified scientific literature (cf. Sections 2.1 and 2.2). For practice-related sources we referred to the two IT magazines *CIO Magazine* and *MIT Technology Review*, as well as the two internet pages *Silicon.com* and *InformationWeek.com*, which report regularly on the topic of Cloud Computing. We reviewed about 450 practitioner articles dating from the year 2007 or later by means of a quantitative content analysis. Furthermore, Martens et al. (2011) analyzed Cloud Computing services in an online database that comprises about 200 Cloud Computing services (cf. www.cloudservicemarket.info). These sources provided additional valuable information for the requirements analysis and for the empirical and theoretical basis of the model. The results of the requirements and characteristics analysis of Cloud Computing services are listed in Table 4 in the central column and are assigned to the related model elements in the left column. For each of these constructs, references are given in the right column in the table.

In the following we describe the results of the quantitative content analysis and demonstrate its influence on the model construction. Affected model elements are put in brackets. An article on Informationweek.com (Jan. 31, 2009) discussed the adoption of Cloud Computing services by companies:

> Cloud computing has been popular mostly among smaller companies, but large user organizations will shed their inhibitions and adopt cloud services more aggressively this year. […]The promise of cost savings and the ease of subscription-style pricing also will fuel adoption among larger companies.

This shows that there are differences between small and large companies as regards the ease of adoption (adoption simplicity) and the costs induced by the effort of implementing Cloud Computing services (adoption costs). Also, the statement implies that a learning effect can occur which affects marginal adoption costs (adoption costs). This is also implicit in the following citation from the same article:

> 'You need the ability to migrate data from one cloud service provider to another, and there are cloud interoperability scenarios that need to be addressed as well,' notes Matt Edwards, director of the cloud services initiative at TM Forum,(…)

Table 4 Requirements on a formal decision model on Cloud Computing services

Model element	Requirement/Characteristic	References/Sources
Relative service importance	Business Processes	(Weinhardt et al. 2009; Leimeister et al. 2010)
Adoption simplicity	Integration costs; Interoperability	(Braunwarth and Heinrich 2008; Talukder et al. 2010), Practice
Service costs	Pricing (pay-per-use), License Costs	(Armbrust et al. 2010; Martens et al. 2011; Lehmann and Buxmann 2009), Practice
Negotiation costs	License and SLA Management	(Püschel et al. 2009), Practice
Allocation costs	Multisourcing, Provider Management	(Levina and Su 2008), Practice
Coordination costs	SLA Management, Provider Management	(Armbrust et al. 2010), Practice
Adoption costs	Integration costs; Interoperability	(Talukder et al. 2010; Martens et al. 2011), Practice
Maintenance costs	Data transfer costs	(Armbrust et al. 2010), Practice
	Scalability	(Armbrust et al. 2010; Talukder et al. 2010)
	Compliance, Hidden Location, Auditing	(Weinhardt et al. 2009; Armbrust et al. 2010; Martens et al. 2011), Practice
Agency costs	Monitoring	(Leimeister et al. 2010), Practice
	Performance Management	(Talukder et al. 2010; Durkee 2010)
Relative security level	Security, Data Protection	(Gupta et al. 2008; Weinhardt et al. 2009), Practice
Loss of confidentiality	Security, Data Protection	(Gupta et al. 2008; Weinhardt et al. 2009), Practice
	Compliance	(Talukder et al. 2010; Armbrust et al. 2010), Practice
Loss of integrity	Data Manipulation	(Gupta et al. 2008; Talukder et al. 2010), Practice
Loss of availability	Availability	(Weinhardt et al. 2009; Armbrust et al. 2010; Gordon and Loeb 2006; Martens et al. 2011), Practice
	Quality (e. g. response time)	(Braunwarth and Heinrich 2008), Practice

The importance of negotiation (negotiation costs), quality assessment (loss of availability) and compliance (loss of confidentiality) in Cloud Computing is stressed in the following contribution on Informationweek.com (Jun. 23, 2010):

> Negotiators: IT management must help business unit managers with contract negotiations and service-level agreements (SLAs). Also, IT must vet service providers in terms of security and compliance in order to assure upper management of their viability and dependability.

The author recommends establishing strong links between IT and business management (relative service importance). Generally, individual business units usually do not see a necessity to involve the IT department in the deployment of Cloud Computing services, for the services are convenient to use and have low expenditures. The need for the integration of allocation costs, i. e. costs for multisourcing and provider management, is confirmed by market analysts (Silicon.com, June 11, 2008):

> Analyst Gartner say the figures reflect a shift towards multi-sourcing, where companies look to several providers to deliver business and IT services.

Accordingly, multisourcing can reduce Cloud Computing risks and induce higher coordination costs at the same time (Informationweek.com, Aug. 16, 2008):

> There are steps companies can take to minimize the risk, including storing data with multiple service providers and regularly backing up SaaS data on on-premises servers.

In our model maintenance costs include the costs of auditing efforts. Due to the fact that the locations of data centers are often kept secret by the provider, accreditations in the form of certificates become necessary. Alternatively, the user has to take the effort of entering negotiations in order to get access to the data centers (Silicon.com, May 28, 2010):

> While such accreditation [SAS 70 type 2] may be considered sufficient for less sensitive data, it may not be adequate for other more delicate areas where CFOs may prefer to send in their own auditors—if allowed.

In our model, agency costs are incurred by monitoring and performance management. Such efforts are not only necessary for provider monitoring, but also for performance enhancement (Informationweek.com, Nov 28, 2009):

> With cloud computing, it may be more difficult to get to the root of any performance problems, like the unplanned outages (…). Monitoring tools are available to give the cloud customer insight into how well the cloud workloads are performing, so customers aren't totally dependent on the say-so of a cloud vender.

Each Cloud Computing service type has a different inherent security level. The same goes for the different deployment models (public, private and community cloud). Hence, different data protection measures [loss of confidentiality] are required in Cloud Computing (Informationweek.com, Nov. 14, 2009):

> The cloud needs to have multiple, concentric levels of data protection, from individual disk mirroring to robust file systems, to differential remote backups (whether to tape or another disk somewhere)(…)

The loss of integrity due to undesired data manipulation is another significant risk factor, for the user often does not know where and by whom the data are processed (Silicon.com, Dec. 10, 2008):

> The integrity of the data as it passes over other people's systems also raises questions. "The fact that the information could be changed in some way is a risk," said Collins, who added that "the scary thing is the organisations that don't think about this stuff".

Finally, the availability of Cloud Computing services is one of the major security concerns companies are facing. The interruption of data availability has the same effect as a system failure, because it significantly impedes all processes affected. (MIT Technology Review, July 28, 2008):

> Availability is essential in cloud computing, says Thomas Vander Wal, founder of the IT consultancy InfoCloud Solutions. If constant access to information and objects is a requirement, then cloud computing may not be a viable option without alternate solutions.

The construction of the formal mathematical model is based on the research process illustrated in Fig. 1, as recommended by Jenkins (1985). It starts with the analysis of the state of the art and the formulation of a research question. Next, the foundation and conceptualization of the model needs to be determined. To test the model, we conduct some simulation scenarios. Finally we draw conclusions and discuss the limitations and future research of our approach.

3.2 Objective of the model

In practice, IT sourcing decisions in organizations are often highly controversial in terms of a balanced cost-risk ratio

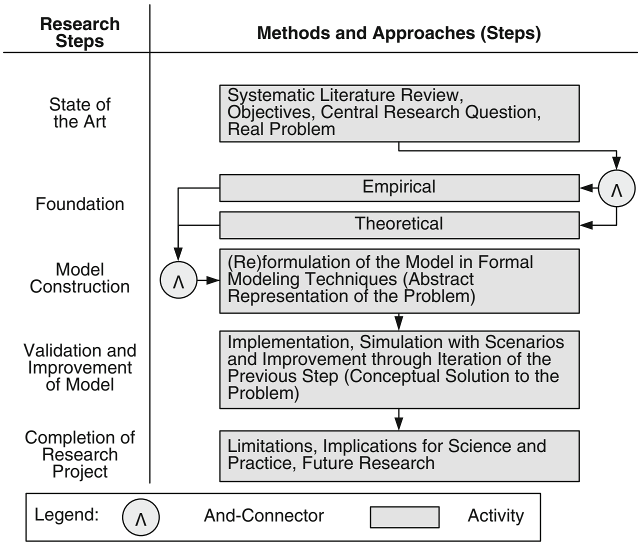


Fig. 1 Research process

(Aubert et al. 2005). Also, most consequences are, at least to some extent, unpredictable and therefore cannot be fully analyzed prior to decision-making. A prominent example of this is the case of Eastman Kodak (Dibbern et al. 2004). Thus, we see a general need for a more solid theoretical and practical foundation and for a stronger focus on cost and risk factors in formal mathematical decision models for the outsourcing of Cloud Computing services.

The model developed here is meant to act as a cost minimization tool, that is, it is supposed to identify the Cloud Computing service or the combination of services which causes the lowest possible cost for an organization by taking cost, risk, security and quality issues into account. The model also allows for the splitting of an IT service into several subservices that can be delivered by a variety of providers who may apply different sourcing models. In our model we followed the approach by Simon (1990) who, in view of the complexity of real-world conditions, focused exclusively on criteria that have a direct impact on the successful performance of the model.

4 Developing a formal decision model

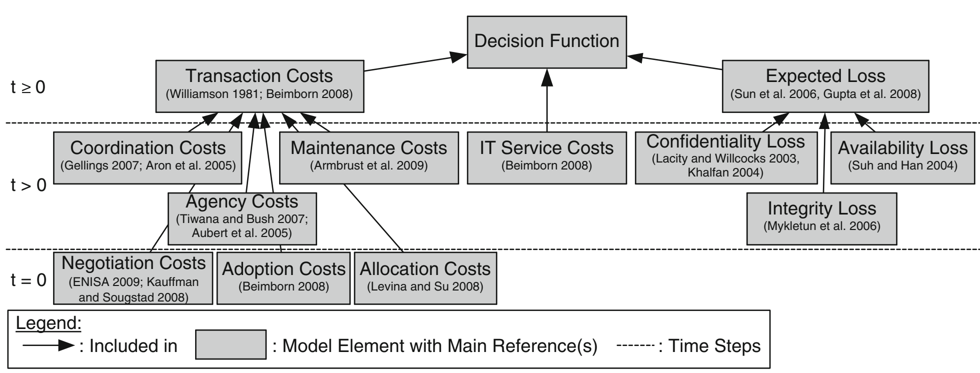
4.1 Overview and general assumptions

In order to visualize our model (cf. Fig. 2), we illustrated the main links between the equations by connecting them through directed edges. The direction of an edge indicates the absorption of an equation in another equation further up in the hierarchy. This hierarchy is based on three different time periods during which costs occur or are discounted to the decision period. For each of the model elements, the sources from which they were derived are given.

Our model is based on two main constructs. The first part considers costs which occur prior to and after the conclusion of a contract between a provider and a user company and is combined to transaction costs. A Cloud Computing service specific cost function which includes fixed and/or variable cost factors as direct costs is presented by the equation for IT service costs. The other part of the model depicts the consideration of risks in the form of expected loss due to exploited vulnerability. We differentiate between the three most common IT security objectives: confidentiality, integrity and availability (Bishop 2002), since they serve best as basic risk factors and fit to the characteristics of Cloud Computing services (Talukder et al. 2010).

The model rests on the basic assumption that IT services support business processes. This approach is called activity based view, whereas an activity can assume the shape of an IT service which in turn deploys resources and generates a measureable output (Lammers 2004). As a general precondition for both the risk and the cost construct, we assume that the user company has unrestricted access to capital markets. As in most other types of formal models, it is assumed that all variables remain constant over time (Beimborn 2008). We know that such a model neither covers the real world's complexity nor could it be complete by means of model elements. However, we tried to include a wide range of theories to

Fig. 2 Overview of the model



consider generically most cost and risk factors inherent in a sourcing decision.

4.2 Relative service importance

As our model relies on the principle that IT services support business processes it is important to determine their interrelations. To avoid direct fault-prone estimations of the variable relative service importance Θ_k^{rel}, which is included in several equations of the model, we developed an analytic hierarchy process (AHP) (cf. Suh and Han 2003). For further description we distinguish three different variables for the importance of a service: Θ_{km} is the basic importance variable (service importance) of service k for business process m which needs to be determined by the decision maker. If the importance weight Θ_{km} is near 1, the business process could not be properly run without the IT service. If it is near 0, the service has only a supporting function. Θ_k^{pre} is the preliminary service importance of service k and includes the business process importance BPI_m of business process m. It is calculated by means of Eq. 1.

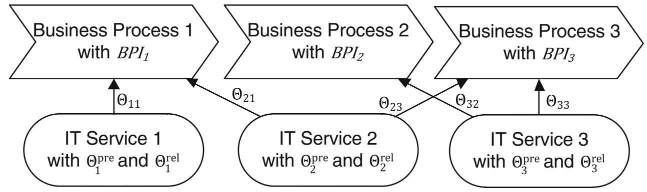
$$\Theta_k^{pre} = \frac{1}{m}\sum_m \Theta_{km} \cdot BPI_m \forall k \tag{1}$$

Finally we use the relative importance Θ_k^{rel} for service k, which directly affects the model. It includes the dependency parameter DP_{km} for service k and business process m and is based on a binary variable {1;0}. The relative service importance is described in Eq. 2.

$$\Theta_k^{rel} = \max_k \left(\Theta_k^{pre} \cdot DP_{km}\right) \tag{2}$$

An example for the calculation of Θ_k^{rel} and DP_{km} with three services and three business processes is given in Table 5 and Fig. 3. In the example business process 1 is supported by IT services 1 and 2, thus the maximum of $\Theta_1^{pre} \cdot DP_{11}$ and $\Theta_2^{pre} \cdot DP_{21}$ needs to be determined by considering the dependency parameter DP_{km} (cf. Eq. 2). DP_{km} can be determined on the basis of the dependency diagram and matrix.

With this paired comparison technique the mutual influence of IT services and business processes becomes measurable. Due to this rating approach it is not necessary to determine the number of activities that an IT service supports or to know at which stage of the business process the supported activities happen. Also, this approach could be adjusted for the assessment of risk factors, which is described in the risk considerations of this model (cf. Section 4.4).



DP_{km}	Business Process 1	Business Process 2	Business Process 3
IT Service 1	$DP_{11}= 1$	$DP_{12}= 0$	$DP_{13}= 0$
IT Service 2	$DP_{21}= 1$	$DP_{22}= 0$	$DP_{23}= 1$
IT Service 3	$DP_{31}= 0$	$DP_{32}= 1$	$DP_{33}= 1$

Fig. 3 Dependency diagram and matrix for IT services and business processes

Generally, Suh and Han (2003) recommend managers of business processes and sub-processes to rely on existing strategic plans (for a first overview and assessment) and the Delphi technique to determine Θ_{km} and BPI_m. More precise, the calibration of Θ_{km} can be done through several alternative methods. For instance, it can be derived by asking employees to respond to constant-sum scales such as used to measure the relative importance of the SERVQUAL dimensions (Parasuraman et al. 1988). SERVQUAL is a common standardized approach for service quality assessments. For a more precise calculation internal data sources like key performance indicators or company indices can also be used to derive baseline estimates. For example, the business process importance BPI_m of business process m can be calculated by determining its sales contribution. Finally the dependency parameter DP_{km} can be derived from the IT architecture and the business process documentation.

4.3 Cost considerations

As an introduction to the cost model we discuss its basic constructs and variables. We mainly distinguish between costs that can be associated with transaction cost theory or direct Cloud Computing service costs (production cost theory). In detail, the transaction costs are distinguished into costs incurred during the decision period t=0 (nego-

Table 5 Assignment of IT services to business processes

	Business process 1 with BPI_1	Business process 2 with BPI_2	Business process 3 with BPI_3	Preliminary service importance Θ_k^{pre}	Relative service importance Θ_k^{rel}
IT Service 1	Θ_{11}	Θ_{12}	Θ_{12}	Θ_1^{pre}	Θ_1^{rel}
IT Service 2	Θ_{21}	Θ_{22}	Θ_{23}	Θ_2^{pre}	Θ_2^{rel}
IT Service 3	Θ_{31}	Θ_{32}	Θ_{33}	Θ_3^{pre}	Θ_3^{rel}

tiation, allocation and adoption costs) and costs incurred during the subsequent periods $t \geq 0$ (maintenance, coordination and agency costs). Most of the formulas include a parameter "*c*" representing the cost basis. The cost basis consists of expenses for required manpower or consulting services. Some tasks that need to be fulfilled are, for example, implementation, negotiation, maintenance or other activities necessary for decision-making and for the procurement and implementation of Cloud Computing services (Hulthén 2009). The nomenclature for the formulation of cost formulas is shown in Table 6. Throughout the model description, each variable is explained in detail.

Several advantages of a multisourcing approach are repeatedly mentioned in the literature, as e. g. risk reduction

Table 6 Nomenclature for the cost parameterization

Symbol	Description
BPIm ∈ [0;1]	business process importance
B_k	budget constraint for service k
C_{ik}^{AD}	adoption costs for service k with sourcing option i
C_{ik}^{F}	fixed costs for service k with sourcing option i
C_{ik}^{O}	overall costs for service k with sourcing option i
C_{ik}^{S}	direct costs for service k with sourcing option i
C_{ikt}^{AG}	agency costs for service k with sourcing option i in period t
C_{ikt}^{C}	coordination costs for service k with sourcing option i in period t
C_{ikt}^{N}	negotiation costs for service k with sourcing option i in period t
C_{k}^{AL}	allocation costs for service k
C_{sikt}^{M}	maintenance costs for the part s of service k with sourcing option i in period t
$DP_{km} \in \{0;1\}$	dependency parameter for service k and business process m
TC_{ikt}	transaction costs for service k with sourcing option i in period t
c_{ik}	variable unit costs for service k with sourcing option i
c_{ikt}^{AG}	agency cost basis for service k with sourcing option i
$c_{ikt}^{AG,ext}$	external agency costs for service k with sourcing option i
$c_{ikt}^{AG,ext}$	internal agency costs for service k with sourcing option i
c_{k}^{AD}	adoption cost basis for service k
c_{k}^{AL}	allocation cost basis for service k
c_{k}^{M}	maintenance cost basis for service k
c_{k}^{N}	negotiation cost basis for service k
$n_i \in [0;1]$	negotiation difficulty for sourcing option i
$o_{it} \in \mathrm{N}^+$	number of realized sourcing projects with sourcing option i up to period $t_0 - 1$
$s_{ik\tau} \in [0;1]$	decision variable to source IT service k with sourcing option i in period(s) τ
w_k	adoption parameter for service k
x_{ikt}	service quantity (usage-dependent) for service k with sourcing option i in period t
y_{ikt}	usage-independent variable for service k with sourcing option i in period t
$\Theta_{km} \in]0;1[$	importance of IT service k for business process m
$\Theta_{k}^{pre} \in]0;1[$	preliminary service importance
$\Theta_{k}^{rel} \in]0;1[$	relative importance of service k
$\zeta_{kij} \in [0;1[$	adoption simplicity for service k between sourcing option i and j
I with $i,j \in I$	set of sourcing options i and j
T	number of analyzed periods, duration of contract
i, j with $i \neq j$	sourcing option (e. g. provider 1)
ir	interest rate
k	IT service indices
m	business process
$t;\ \tau = T - t$	period(s)
$\nu \in [0;1]$	allocation quota
β	negative exponent for the formulation of a learning process
$\gamma \in [0;1]$	relative part of negotiation and allocation costs

and increased supplier innovation, but also disadvantages like increased management overhead and higher transaction costs (Levina and Su 2008). The popularity of Cloud Computing seems to prove that a multisourcing approach makes sense in some conditions. However, in Section 4.5 we will show that e. g. for software services a multi-sourcing approach is not always beneficial. Thus, we implemented the decision variable $s_{ik\tau}$ for IT service k with sourcing option i in period(s) τ and an continuous parameterization from 0 to 1. Value 0 means that the service is not sourced to a particular sourcing option, whereas value 1 indicates that the service is delivered in only one way. The efforts for this allocation of services to sourcing options are included in the maintenance costs, which will be discussed later, by means of variable $s_{ik\tau}$, and in other equations by means of I as a set (number) of sourcing options i and j. An example for the allocation of three services to three different sourcing options for the period(s) τ is shown in Table 7.

The adoption simplicity parameter ζ_{kij} for service k between sourcing option i and j is used to describe the degree of difficulty with which a service is adopted and depends on former experiences with different sourcing models. The parameter is near 1 if the service and its interface are known from previous experience. If $\zeta_{kij}=0$, the company has to carry the full service adoption costs. An example with 3 sourcing options is presented in Fig. 4. In classic IT outsourcing it is unlikely that ζ_{kij} takes the value of 1 because standardization efforts are not the norm in this field. In contrast, standardization organizations like euro-cloud.org (trade association of European Cloud Computing providers), cloudsecurityalliance.org (aims at increasing the security of Cloud Computing services) or deltacloud.org (development of one API that supports several vendor-specific APIs) have a strong influence on the Cloud Computing industry. Therefore, the parameter takes the value of 1 more frequently in Cloud Computing because standardization organizations contribute significantly to the reduction of implementation efforts.

4.3.1 IT service costs t>0

To formulate a realistic cost function we apply a linear cost function (Beimborn 2008) and introduce the three major

Table 7 Example for the allocation of IT services

Service	Sourcing option 1	Sourcing option 2	Sourcing option 3	Set I
$k=1$	$s_{11\tau}=0.6$	$s_{21\tau}=0$	$s_{31\tau}=0.4$	2
$k=2$	$s_{12\tau}=1$	$s_{22\tau}=0$	$s_{32\tau}=0$	1
$k=3$	$s_{13\tau}=0.7$	$s_{23\tau}=0.2$	$s_{33\tau}=0.1$	3

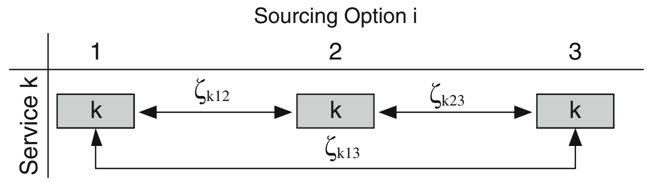


Fig. 4 Example for the adoption simplicity

pricing models for Cloud Computing services (Lehmann and Buxmann 2009): recurring payments on a usage-dependent basis (Amazon Web Services, Elastic Compute Cloud: price per hour; inbound and outbound transferred data traffic), an usage-independent basis (Salesforce.com: price per user and month) or a combination of usage-dependent and usage-independent elements (Amazon Web Services, Elastic Compute Cloud: reservation of further machines). Equation 3a describes the most prevalent model with recurring payments. It includes solely an usage-dependent part (c_{ik}, x_{ikt}), with c_{ik} as variable unit costs incurred through service k and sourcing option i and x_{ikt} denoting the procured quantity of service k in period t. The next Eq. 3b presents the classic SaaS-scheme with a fixed part $\left(C_{ik}^F\right)$ and the usage-independent variable y_{ikt}. Finally, we introduce Eq. 3c with a combination of a fixed part that could be a function of y_{ikt} and the usage-dependent part. The fixed costs could be setup, maintenance or reservation costs as shown in the example. Further price discriminations by means of volume discount or a minimal order quantity (Lehmann and Buxmann 2009) are considered by confining the range of values by a lower bound (LB) and an upper bound (UB) (cf. Eq. 3d). Finally we added to each pricing model the decision variable $s_{ik\tau}$ to determine the quota of service k sourced to sourcing option i in period(s) τ.

$$C_{ikt}^S = c_{ik} \cdot x_{ikt} \cdot s_{ik\tau} \tag{3a}$$

$$C_{ikt}^S = C_{ik}^F \cdot y_{ikt} \cdot s_{ik\tau} \tag{3b}$$

$$C_{ikt}^S = C_{ik}^F(y_{ikt}) + (c_{ik} \cdot x_{ikt}) \cdot s_{ik\tau} \tag{3c}$$

$$Subject\ to: C_{ikt}^S \in (LB, UB) \tag{3d}$$

4.3.2 Negotiation costs in t=0

In our model, the costs C_{ikt}^N of negotiating the contract and the SLAs for service k with sourcing option i in period t depend on two constructs (cf. Eq. 4). First we parameterized the learning curve effect $\left((o_{it}+1)^{-\beta}\right)$, i.e. cost reductions achieved through experiences gained with former projects involving IT outsourcing (Braunwarth and Heinrich 2008; Tsang 2000). The variable o_{it} determines the number of realized sourcing projects with sourcing option i up to period $t_0 - 1$ and is influenced by the exponent β, which is declared as a specific learning variable that can be chosen by the company. A realistic and empirically tested value for β is for instance 0,9 (Beimborn 2006). The first part of this equation will take the value of 1 for o_{it}=0 (no effect on the negotiation costs) and 0,37 for o_{it}=2 (the learning parameter reduces the value of the negotiation costs). Overall, the learning parameter has a high influence on the negation costs. This is a realistic assumption for Cloud Computing services as we discussed already for the adoption simplicity parameter. The last term in the formula extends the negotiation costs by the negotiation difficulty n_i for sourcing option i.

On the one hand, SLAs and the prices of Cloud Computing services are often not negotiable (ENISA 2009), and a company always strives to select the best-fit services and providers with minimal negotiation efforts. On the other hand, negotiation difficulty also depends on the number and types of contractual parameters such as service levels, service quality, timeliness, as well as on related penalties or incentives (Kauffman and Sougstad 2008). Empirical evidence is provided by Martens et al. (2011) who analyzed about 170 Cloud Computing services with regard to information on SLAs, certificates and prices. They found that most of the providers include information on certificates, but none on SLAs or prices on their websites. Only large providers offer extensive information on these issues.

$$C_{ikt}^{N} = c_k^N \cdot (o_{it} + 1)^{-\beta} \cdot (n_i + 1) \; \forall i, k, t_0 - 1 \tag{4}$$

4.3.3 Allocation costs in t=0

In our model we decided to implement the possibility of a multisourcing approach. As soon as a user company takes up simultaneous negotiations with different providers, the transaction costs rise. To parameterize the allocation function, we use the allocation quota v on a logarithmic base (cf. Eq. 5). Thus the allocation costs C_k^{AL} of service k increase with the number of sourcing options in set I that contains the applied number of different sourcing options i and j (cf. Eq. 6).

$$v = \frac{1}{I} + \ln I \tag{5}$$

$$C_k^{AL} = c_k^{AL} \cdot v \; \forall k \tag{6}$$

4.3.4 Coordination costs in t>0

The ex post administration and coordination of the sourcing contracts and SLAs are considered in our model, since notions like “vendor holdup” shape the timeframe after the conclusion of contracts (Aron et al. 2005). The vendor acts opportunistically and renegotiates the established contract regarding prices and SLAs, when the client discovers that it has no alternative sourcing option due to a vendor lock-in, for instance. Open issues in this stage are the adaption of change requests and renegotiations (Aubert et al. 2005). For the mathematical parameterization, the coordination costs C_{ikt}^{C} for service k with sourcing option i in period t are built on the negotiation costs C_{ikt}^{N} and allocation costs C_k^{AL} and complemented by a multiplicative variable γ (cf. Eq. 7). We simplified this formula to show that the coordination costs depend on the same factors as negotiation and allocation costs. They do not vary over the time horizon in our model.

$$C_{ikt}^{C} = \left(C_{ikt}^{N} + C_k^{AL}\right) \cdot \gamma \; \forall i, k, t \tag{7}$$

4.3.5 Adoption costs in t=0

It always takes some initial effort to integrate an IT service into the user company’s IT landscape. For instance, costs of adjusting the technical interfaces and additional implementation efforts occur. For the mathematical formulation of adoption costs C_{ik}^{AD} we apply the adoption simplicity parameter ζ_{kij} of service k and sourcing options i and j (cf. Eq. 8). The adoption costs also rise if the user company chooses a set I of different sourcing options. This is modeled by using the adoption parameter w_k for service k which is dependent on I in a logarithmical way like shown in Eq. 9.

$$C_{ik}^{AD} = c_k^{AD} \cdot \left(1 - \zeta_{kij}\right) \cdot w_k \; \forall k, i, j \tag{8}$$

$$w_k = \ln I \textit{ with } i \neq 1 \tag{9}$$

4.3.6 Maintenance costs in t>0

Maintenance costs C_{ikt}^{M} (for service k with sourcing option i in period t) are distinguished from adoption costs because the costs of data transfer and the human interaction necessary for the continuous operation of the IT service occur in periods greater than 0. The cost basis of the maintenance costs include costs for internal IT infrastructure and costs for the internet service provider to enable the data transfer as well as direct data transfer costs between the provider and the user company. Additionally costs for technical service and maintenance and further costs to establish the proper service operation need to be included as well. Brandl et al. (2007) developed a framework to identify and calculate internal costs of IT infrastructures and consolidate them for particular services. This approach can support companies in calculating the maintenance costs for the model. Costs for compliance tasks like auditing are included here as well. These efforts ensure the operational interplay between in-house and outsourced processes and are based on both the transaction cost and production cost theory. They are correlated with the service output quantity x_{ikt} and the decision variable $s_{ik\tau}$ for period(s) τ (cf. Eq. 10, (Beimborn 2008; Armbrust et al. 2010)).

$$C^M_{ikt} = c^M_k \cdot x_{ikt} \cdot s_{ik\tau} \; \forall\, i, k, t \tag{10}$$

4.3.7 Agency costs in t>0

Agency costs root in the relationship between principle (user company) and agent (provider) (Tiwana and Bush 2007; Aubert et al. 2005). Relevant cost factors in this context can be divided into monitoring costs (i.e. observing the provider's actions), bonding costs (i.e. rewarding good provider performance) and residual loss (i.e. due to the provider's inadequate coordination or motivation) (Tiwana and Bush 2007). For example, monitoring costs are incurred by the establishment of a performance measurement system in the form of SaaS. Bonding costs and residual loss depend on the degree of automation. Large providers with a high degree of automation are generally immune to bonding costs; rather, they offer their customers bonus services if SLAs are not fulfilled. Accordingly, smaller providers are more receptive for bonding payments. Since agency costs are difficult to measure we apply a form of proxy (Ogawa and Iiboshi 2008). Agency costs, as they are implicated in this model, represent the difference between external and internal agency costs. This assumption offers an easy determination of the agency costs like Jensen and Meckling (1976) show. To calculate the agency costs C^{AG}_{ikt} for service k with sourcing option i in period t, we apply the relative service importance Θ^{rel}_k again (cf. Eq. 11).

$$C^{AG}_{ikt} = c^{AG}_{ikt} \cdot \Theta^{rel}_k \; \forall i, k \tag{11}$$

$$\textit{Subject to}: c^{AG}_{ikt} = c^{AG,ext}_{ikt} - c^{AG,\text{int}}_{ikt} \tag{12}$$

4.3.8 Decision basis

To summarize the transaction costs, we differentiate the time steps t=0 and t>0, that we analyze within the model (cf. Eqs. 13 and 14). The sourcing costs for IT services are summarized in Eq. 15 to C^O_{ik} and show that costs which occur in the analyzed time period from the first period t to the last period T are summed up. The first part of the formula $\left(\left(C^S_{ikt}(x_{kt}) + TC_{ik(t>0)}\right) \cdot (1+ir)^{-t}\right)$ contains the direct service costs $C^S_{ikt}(x_{kt})$ and transaction costs from t>0. In discounting these costs we follow Singh et al. (2004) who argue that a sourcing decision should be treated like an IT investment decision. The second part $\left(TC_{ik(t=0)}\right)$ contains costs occurring in the decision period 0.

$$TC_{ik(t=0)} = C^N_{ikt} + C^{AL}_k + C^{AD}_{ik} \tag{13}$$

$$TC_{ik(t>0)} = C^{AG}_{ikt} + C^C_{ikt} + C^M_{ikt} \tag{14}$$

$$C^O_{ik} = \sum_t^T \left(C^S_{ikt}(x_{kt}) + TC_{ik(t>0)}\right) \cdot (1+ir)^{-t} + TC_{ik(t=0)} \; \forall i, k \tag{15}$$

4.4 Risk considerations

The risk-related part of our model supports the risk assessment phase of a typical risk management process. To apply the presented risk definition (cf. Section 1), it is necessary to identify potential negative outcomes. Cloud Computing services are exposed to a high degree of risks that result from technical issues (e. g. data availability) or data access issues (confidentiality) (Talukder et al. 2010). Thus, we formalized three most common IT security objectives: confidentiality, integrity and availability (Bishop 2002). These three objectives form a solid basis which could be extended in practice by more detailed and specific security objectives like authentication, authorization, accounting, and anonymity (Sackmann et al. 2009; Talukder et al. 2010). This technical approach to IT security risks seems adequate for the investigation of Cloud Computing services (Yunis 2009; Martens et al. 2011). The nomenclature for this section is given in Table 8 and in the following described in detail.

To build a consistent model we parameterize risk factors in a similar way as the cost considerations and include in each formula the expected loss basis l^e_{ik} for the violation of a security objective e for service k and sourcing option i as a cost basis for the particular risk factors. This loss basis declares the average loss per unit and depends on the service output quantity x_{kt} for service k in period t. We follow the approach by Hulthén (2009) who argues that the loss bases include costs for problem

Table 8 Nomenclature for the parameterization of risks

Symbol	Description
e	IT security objective
$C \in e$	confidentiality of IT security objective e
$I \in e$	integrity of IT security objective e
$A \in e$	availability of IT security objective e
SOI_{em}	importance of security objective e for business process m
$\Phi_{ek} \in]0;1[$	contribution of service k to security objective e
$\Phi_k^{rel} \in]0;1[$	relative contribution to security objective e
L_{ik}^e	loss due to violation of a security objective e for service k and sourcing option i
l_{ik}^e	expected loss basis for the violation of a security objective e for service k and sourcing option i
$P_{ik}^e \in]0;1[$	overall probability of the violation of security objective e for service k and sourcing option i
$P_{ik}^{e+} \in]0;1[$	probability of the violation of security objective e for service k and sourcing option i
$P_{ik}^{e-} \in]0;1[$	probability of the non-violation of a security objective e for service k and sourcing option i
$P_{ik}^{eu} \in]0;1[$	probability of the uncertainty about p^{e+} or p^{e-} for service k and sourcing option i
RA $\in]0;1[$	risk attitude of the decision maker
x_{kt}	service output quantity for service k in period t
x_{kt}^f	output quantity during period t of service failure f
$\alpha>0$	learning process variable
$v^{e,mod}$	modified allocation quota for IT security objective e
L_{ik}^O	overall losses for sourcing service k to sourcing option i
SV_τ	Sales volume of the company under consideration in period(s) τ

solving, continuity management, stand-still time, lost revenue, costs for lawsuits, customer compensations and further direct costs caused by the mitigation of risk exposure. Finally this basic formula is multiplied with the probability of risk exposure P_{ik}^e of security objective e for service k and sourcing option i (Hulthén 2009). Generally, sources for information on risk data can be collected internally, for instance Hulthén (2009) provides some empirical data of a case study. Data for the calculation of loss per unit are exemplified by Cohen (1999) that conducted a simulation study. For the modeling of risk factors in Cloud Computing we assume that the correlation between the risk factors equals 0, to show that they are independent.

Again, we adopt and adjust the AHP approach (cf. Section 4.2), focusing on IT security objectives (instead of business processes cf. Fig. 3). The purpose is to determine the relative security contribution Φ_{ek}^{rel} to which an IT service k contributes to an IT security objective e. In mathematic terms the security contribution Φ_{ek} of service k to security objective e is multiplied with the security objective importance SOI_{em} of security objective e for business process m (in place of the business process importance (BPI_m) as described in Section 4.2) and result in a value per security objective e that is included in the following equations for confidentiality, integrity and availability (cf. Eq. 16 and Table 9). The variable Φ_{ek} does not change during the analyzed time period.

$$\Phi_{ek}^{rel} = \frac{1}{m} \cdot \sum_m (\Phi_{ek} \cdot SOI_{em}) \ \forall e, k \tag{16}$$

The dependency diagram and the calculation of the preliminary security contribution are obsolete at this stage, since each IT service should support each security objective. The variables SOI_{em} and Φ_{ek} can be determined by risk managers, system managers or information security professionals. This approach is frequently adopted in the literature (Gupta et al. 2008).

We consider the *overall* probability of risk exposure P_{ik}^e of security objective e for service k and sourcing option i in each formula and complete it by the learning parameter α in the equations for confidentiality and integrity in the following (Lacity et al. 2009). The probability of risk exposure P_{ik}^{e+} can be determined by means of the method suggested by Sackmann et al. (2009). They apply the Common Vulnerability Scoring System and adjust it to security objectives.

To include the representation of the risk attitude of the decision maker in our model, we implemented parameter RA that has a range from near 0 (risk seeking) to near 1 (risk averse). We enclose an approach used by Sun et al. (2006) and differentiate between three probabilities. First the probability of risk exposure P_{ik}^{e+} as mentioned above, second the converse probability of non-exposure P_{ik}^{e-} and finally the uncertainty about these two values P_{ik}^{eu} (residual

Table 9 Assignment of IT services to IT security objectives

	IT security objective importance			Relative security contribution		
	Confidentiality SOI_{Cm}	Integrity SOI_{Im}	Availability SOI_{Am}	Confidentiality Φ_{Ck}^{rel}	Integrity Φ_{Ik}^{rel}	Availability Φ_{Ak}^{rel}
IT Service 1	Φ_{C1}	Φ_{I1}	Φ_{A1}	Φ_{C1}^{rel}	Φ_{I1}^{rel}	Φ_{A1}^{rel}
IT Service 2	Φ_{C2}	Φ_{I2}	Φ_{A2}	Φ_{C2}^{rel}	Φ_{I2}^{rel}	Φ_{A2}^{rel}

probability). All three values are added to 1 (cf. Eq. 17). The final calculation of the *overall* probability P_{ik}^{e} is presented in Eq. 18. If P_{ik}^{e} is near 1 (high probability), the learning parameter α can only weakly influence the term. This approach captures as well the residual loss inherent in every decision.

$$P_{ik}^{e+} + P_{ik}^{e-} + P_{ik}^{eu} = 1 \tag{17}$$

$$P_{ik}^{e} = P_{ik}^{e+} + RA \cdot P_{ik}^{eu} \tag{18}$$

4.4.1 Loss due to the violation of confidentiality

Companies take high risks if they outsource highly sensitive data to the cloud. Confidentiality, i. e. making data accessible for authorized users only (Gordon and Loeb 2006), serves to mitigate these risks. Lacity and Willcocks (2003) found out that in IT outsourcing contracts this risk factor is one of the most frequently mentioned issues. The same is true for Cloud Computing services, for the execution environment is shared (multi-tenant architecture) and the user company lacks control over the provider's IT infrastructure, which results in problems of confidentiality and integrity (Christodorescu et al. 2009). Pursuing a multisourcing strategy Levina and Su (2008) argue that each supplier is less critical, since he processes less sensitive data and the operational as well as the strategic risk is reduced. For the parameterization of this factor the allocation quota ν (cf. Eq. 5) is included in a modified form (cf. Eq. 19). The value of $\nu^{C,mod}$ for confidentiality equals 1 if I is 1 with a slow decreasing natural logarithm function. To emphasize the importance of confidentiality as a security objective we implement the relative service importance Θ_{k}^{rel} for service k in Eq. 20.

$$\nu^{C,\mathrm{mod}} = \left(\frac{1}{I} + \ln I\right)^{-1} \tag{19}$$

$$L_{ikt}^{C} = l_{ik}^{C} \cdot x_{kt} \cdot \Phi_{Ck}^{rel} \cdot \left(\Theta_{k}^{rel} + 1\right) \cdot \nu^{C,\mathrm{mod}} \cdot \left(P_{ik}^{C}\right)^{\alpha} \; \forall i,k,t \tag{20}$$

4.4.2 Loss due to the violation of integrity

Integrity violations can lead to loss or manipulation of data that are stored or processed in a provider's data center (Gordon and Loeb 2006). As a general rule, the integrity of outsourced data must always be regarded as potentially threatened, if the data in not encrypted properly (Mykletun et al. 2006; Cloud Security Alliance 2009). To parameterize this problem we supplement our equation with a modification of the allocation quota $\nu^{I,mod}$, which increases weaker than $\nu^{C,mod}$ (cf. Eq. 21). However, Eq. 22 includes the same variables as in 20.

$$\nu^{I,\mathrm{mod}} = 1 - \ln\left(\frac{1}{I}\right) \tag{21}$$

$$L_{ikt}^{I} = l_{ik}^{I} \cdot x_{kt} \cdot \left(1 - \Phi_{Ik}^{rel}\right) \cdot \nu^{I,\mathrm{mod}} \cdot \left(P_{ik}^{I}\right)^{\alpha} \; \forall i,k,t \tag{22}$$

4.4.3 Loss due to the violation of availability

Another important security objective is the availability of an IT service that provides timely access to information for authorized users (Gordon and Loeb 2006). Examples are response time and uptime of server, which belong to quality issues of Cloud Computing services (Püschel et al. 2009). High availability is essentially important because during periods of service failure outsourced data are usually neither accessible via the internet nor directly via the data center, because of potential high distances. Therefore, in Eq. 23, x_{kt}^{f} is the output quantity in period t with failure of service k. The expected loss basis l_{ik}^{A} for service k and sourcing option i encompasses the costs of switching a provider and other efforts to make the service available again (Suh and Han 2003; Hulthén 2009). The loss in sales per output quantity for sourcing option i is included in l_{ik}^{A}.

$$L_{ikt}^{A} = l_{ik}^{A} \cdot x_{kt}^{f} \cdot \left(1 - \Phi_{Ak}^{rel}\right) \cdot P_{ik}^{A} \; \forall i,k,t \tag{23}$$

4.4.4 Decision basis

The costs of expected loss due to the consideration of risks are incurred during periods $t>0$, since services are applied in this periods first. These costs are simply added and finally discounted to $t=0$ with ir as interest rate. Equation 24 represents the discounted overall expected loss L_{ik}^{O} for service k and sourcing option i and includes the decision variable $s_{ik\tau}$.

$$L_{ik}^{O} = \sum_{t}^{T} \left(L_{ikt}^{C} + L_{ikt}^{I} + L_{ikt}^{A}\right) \cdot s_{ik\tau} \cdot (1 + ir)^{-t} \; \forall i,k \tag{24}$$

4.5 Decision calculus and constraints

4.5.1 Decision function

The basic decision function for the whole model results from the addition of Eqs. 15 (overall costs for Cloud Computing services) and 24 (expected loss). Through this combination of equations the target function is minimized.

$$\sum_{ik} \left(C_{ik}^{O} + L_{ik}^{O}\right) \rightarrow \min \tag{25}$$

4.5.2 Constraints

The model includes constraints for a realistic picture of the decision scope and the decision environment. First, the decision variable $s_{ik\tau}$ to source service k to sourcing option i in period(s) τ could be split and allocated to different sourcing options (cf. Eq. 26). The total needs to equal 1.

$$\sum_i s_{ik\tau} = 1 \ \forall k\tau \tag{26}$$

The user company may be bound to an Cloud Computing service for a longer period of time, for contractual or economic reasons. For example, the costs caused by backsourcing or switch a provider may turn out to be unreasonably high. As Whitten and Wakefield (2006) have shown, there are multiple reasons for the phenomenon of high switching costs (e. g. pre-switching search costs, lost benefits and post-switching costs) which are of great importance for managerial outsourcing decisions. Equation 27 presents this constraint and includes decision variable $\overline{s_{lk\tau}}$ as numerically fixed to time period τ.

$$\overline{s_{lk\tau}} \ \forall \tau \tag{27}$$

Moreover, in some conditions the splitting of service k and sourcing it to $i>1$ different sourcing options could result to an inefficient allocation. This occurs often for software services and causes for example data redundancy and thus to a higher workload. Therefore, we introduce a constraint which compensates this problem. For the mathematical formulation we apply the relative service importance Θ_k^{rel} and sales volume SV_τ in period(s) τ of the focal company which are defined as the value proposition of service k (cf. Eq. 28).

$$\Theta_k^{rel} \cdot SV_\tau \ with \ s_{ik\tau} \geq \Theta_k^{rel} \cdot SV_\tau \ with \ s_{Ik\tau} \tag{28}$$

We added a budget constraint with budget B_k for service k to the decision function in order to identify the optimal service that achieves the right balance of risks $\left(L_{ikt}^O\right)$ and costs $\left(C_{ikt}^O\right)$ (cf. Eq. 29). In case of tight budgets, a heuristic solution can be arrived at by modifying the risk attitude of the decision maker.

$$B_k \geq \sum\nolimits_{ik} C_{ik}^O + L_{ik}^O \tag{29}$$

Finally we provide a constraint that proofs the efficiency (cost benefit ratio) of the model and covers the value proposition $\Theta_k^{rel} \cdot SV_\tau$ of service k. Equation 30 needs to be valid, since the value proposition should be greater or equal to the calculated costs and risks.

$$\Theta_k^{rel} \cdot SV_\tau \geq \sum\nolimits_{ik} C_{ik}^O + L_{ik}^O \tag{30}$$

Nonnegativity constraints for the model are presented in Eqs. 31 and 32. Variables that are not defined explicitly in the model are elements of $\mathbb{N}^+$.

$$x_{ikt} \geq 0 \ \forall ikt \tag{31}$$

$$c_{ik}, c_i \geq 0 \ \forall ik \tag{32}$$

5 Application and validation of the model

5.1 Theoretical considerations for solving the model

The presented model describes a discrete dynamic optimization problem, for in each period the required quantity (e. g. storage capacity in gigabyte) needs to be determined. Thus, there is no single optimal solution to this problem. Rather, algorithms like the simplex approach are not applicable, for some equations are non-linear, the problem is discrete and it does not provide extensive constraints to formulate a system of equations. Additionally, mutually exclusive requirements (as, for instance, highest possible security and lowest possible costs) require more sophisticated approaches. Since we did not directly include risk mitigation efforts in the model and took a pure loss perspective on risk factors, mutually exclusive requirements cannot occur. We assume that risk mitigation efforts are already included in the market prices of Cloud Computing services, for providers have to take several security measures regarding their data center and IT architecture. Thus, the market prices of Cloud Computing services with high security standards are comparatively high.

Generally, the model analysis on the basis of $t \geq 4$ periods is advisable to enable a comparison between Cloud Computing services and other IT investments. Theoretically, the model can be solved by means of a specific dynamic programming approach to which no standard algorithms apply. By and large, the model shows structural similarities to other sourcing problems, as e. g. the model by Beimborn (2008) and Knolmayer (1997) who argue that such a model cannot be solved by means of exact (non-heuristic) optimization procedures within an adequate time frame and thus it is a NP-hard problem. An efficient heuristic approach to this problem would be a genetic algorithm (Beimborn 2008).

5.2 Configuration of the model

In this article we presented a comprehensive model which accounts for a wide range of cost and risk factors of Cloud Computing services. However, the practical application of such an sophisticated model will not always be feasible due to the effort caused by data and information collection. The presented approaches for the determination of variables (e. g. the determination of the relative service importance in Section 4.2) further increase the effort unless other less complex assessment approaches are chosen instead. As a result, we developed additional configurations of the model to meet individual business requirements (cf. Table 10). We distinguish three types of model configurations (basic, intermediate and complete configuration) and describe which model elements are included or excluded, how many variables need to be determined and the amount of estimation effort needed for each configuration. In addition, we provide information on possible data sources for the model elements in Table 10. The basic configuration omits complex assessment approaches and variables, but includes simple estimations (as highlighted in the table) of important variables. This model offers a simple cost and risk assessment of outsourced IT services that may be classified as support services, as e. g. infrastructure services. Furthermore, the intermediate configuration contains all variables, but omits individual assessment approaches. It is more suitable for Cloud Computing services that do not affect the company's income to a great extent. Finally, the complete model contains the entire set of variables and approaches. It should be applied to Cloud Computing services that support core business processes which are critical for business continuity as, for example, certain software services. A sourcing decision is also influenced by other factors, as e. g. data availability and the volume of historical data on business processes. Nevertheless, the presented configurations of our model are neither fixed nor limited and could therefore be further modified in order to meet particular requirements. In the table, we have also provided additional information on the data collection effort and the complexity of the model.

Another way to reduce the complexity of the model is the modification of the decision variable $s_{ik\tau}$. Again, three different varieties are possible. The model can be used as a cost comparison tool for the sourcing of one service k to one sourcing option i; as allocation approach for the sourcing of a set of services K to one sourcing option i and as a multisourcing model for the sourcing of a set of services K to a set of sourcing option I, as described above. The inherent complexity of the decision problem ranges from the minimal number of decision variables S=K to the maximum number S=$I\cdot K$ (cf. Knolmayer 1997). For example, the sourcing of 3 services to 3 sourcing options could be realized by sourcing all services to one sourcing option $\left(S = 3 | \sum_i s_{it} = 1\right)$ or by splitting and allocating each service to all three sourcing options $\left(S = 9 | \sum_{ik} s_{ikt} = 1\right)$.

5.3 Model implementation and simulation

For the simulation of the model, we decided to solve the model as a costs comparison tool (mostly linear equations) and apply scenario analyses. This method is suitable due to several aspects: First, the literature review has shown that in several approaches linear models or linear equations were used for modeling Cloud Computing services (e. g. Püschel et al. 2009; Cheng et al. 2006). Second, this technique is

Table 10 Example configurations of the model

Model element	Basic	Intermediate	Complete	Data sources
Θ_k^{rel}	not included	simple estimation	included	O
ζ_{kij}	not included	Included	included	O, P
Service Costs	included	Included	included	P
Negotiation Costs	n_i not included	n_i not included	included	O, P
Allocation Costs	included	Included	included	O
Coordination Costs	complete estimation	Included	included	O
Adoption Costs	ζ_{kij} not included	Included	included	O, P
Maintenance Costs	$s_{ik\tau}$ and Θ_k^{rel} not included	$s_{ik\tau}$ not included	included	O, P, I
Agency Costs	Θ_k^{rel} not included	Included	included	O, P
Φ_k^{rel}	not included	simple estimation	included	O
P_{ik}^e	simple estimation	simple estimation	included	O, I
Loss of Confidentiality	Φ_k^{rel} and Θ_k^{rel} not included	Included	included	O, P
Loss of Integrity	Φ_k^{rel} not included	Included	included	P
Loss of Availability	Φ_k^{rel} not included	Included	included	O, P
Applicable Service Types	IaaS	PaaS	SaaS	
Complexity (# and% of Variables)	11 (42%)	17 (62%)	26 (100%)	
# of Equations	11	14	18	
Estimation Efforts	low	Medium	high	

O Outsourcer (decision-making company); *P* Provider; *I* Industry informative in theory and helpful in practice. In the structuring of scenarios we followed the example of Cha et al. (2008) who simulated and analyzed a formal mathematical model for IT offshoring. The main objective is to show that decision makers are overwhelmed by the request to evaluate such a huge amount of data. The implementation of the model is done with FICO Xpress Optimizer, since it is a common mathematical optimization software tool that offers several linear and non-linear algorithm as well as a genetic algorithm.

The focal company of the case study is a small to medium sized company and should decide on sourcing storage capacity by means of a Cloud Computing service to one of three different sourcing options (Cloud Computing providers). The IT services are not available via an internal data center instantly (Armbrust et al. 2010). Each provider offers one Cloud Computing service and each of these services has different characteristics as regards security, compliance and quality issues. The direct costs are assumed to be calculated on a variable cost basis (cf. Eq. 3a). Within this configuration the index k always takes the value of 1 because the focal company wants to outsource one particular IT service. For instance variable x_{ikt} will be x_{i1t} within the following analysis. However, this approach does not influence the robustness of the model. Rather, it simplifies its practical application and demonstrates its functionalities.

Sourcing option 1 is a cost-efficient Cloud Computing service with low direct costs. This service uses a common API, which keeps implementation efforts low. The service is optimized for low pricing. Hence, the stored data are not located at one single data center. Instead, the company optimizes the location of data with the aim of improving load balancing and availability. However, new risk factors like the applicable jurisdiction and the data confidentiality need to be assessed. Another issue of this service is that the data is not redundantly stored. *Sourcing option 2* causes medium service costs (from a general market perspective) and does not provide redundant data backup either. Furthermore, the provider developed a company-specific API that increases implementation efforts on the side of the outsourcer. Also, security and compliance issues lead to higher management costs. Finally, *sourcing option 3* provides a high level of security (data encryption for stored and transferred data), redundant data storage, CO_2-neutral service provisioning and a common API. Since this Cloud Computing service is highly compliant with several regulations it is the most expensive one of all services presented in the context of this case study.

For the exploration and presentation of the model we apply three scenarios. In *scenario I*, the outsourcing company (decision-making company) is a newcomer to the field of Cloud Computing. Within the model we set the number of sourcing projects o_{it} to 0. The result are rising implementation costs for the adjustment of the API and increased costs for assuring the technical and process-related interplay between business processes and Cloud Computing services. The service importance Θ_{1m} is set to low values, for the company has little experience with Cloud Computing technologies. Related risk factors are assessed carefully and at a high level of uncertainty. The decision maker in this scenario is risk-averse. *Scenario II* closely refers to Durkee (2010) who accentuates the importance of trust in the service provider, i. e. the basic belief that the provider will act in accordance with the user company's business objectives and contributes to its success. In this scenario, data security plays a more important role because of high risk aversion and the high confidentiality of the processed data. Consequently, the adoption efforts increase through the reduction of the simplicity parameter ζ_{1ij}. However, the company has already gained experience with Cloud Computing and core business processes are strongly impacted by this technology. Finally, *scenario III* is meant to illustrate the application of Cloud Computing services for low confidentiality data. In this scenario the outsourcing company has gained experience with Cloud Computing and employs qualified IT administrators to ensure secure data transfer and storage. Thus, the API is well-known to the employees due to former contracts with provider number 2.

The simulation data are derived from both practical sources and relevant literature. For instance, we analyzed real service offerings in order to adjust the direct Cloud Computing service costs and the data transfer prices of the Cloud Computing provider. Additionally, we consider data transfer costs charged by the internet service provider as well as costs related to the internal IT infrastructure (Matros et al. 2009). Also, we draw on Beimborn (2008) who determined values for parameters like β and γ by means of interviews and a survey. Moreover, the cost bases are calculated on the basis of average salary rates for IT administrators and IT consultants, which range between 200 € and 2,000 € per day (Matros et al. 2009). Finally, parameter values for the risk perspective of the model are derived from the work of Cohen (1999) who conducted a realistic simulation study on security threats and risk factors. For instance, we apply the threat "competitors" for the modeling of data integrity. Bearing in mind that a multi-tenant architecture is frequently applied in Cloud Computing we assume a high level of risk exposure as regards data integrity. Since our focus is on a small to medium sized company we adjusted the remaining variables accordingly. Table 11 contains the values for fixed parameters within our case study, while Table 12 lists the adjusted parameters to differentiate between the exemplified scenarios. At the bottom of the table we include the results of the cost and risk perspective as well as the overall costs.

Table 11 Settings for fixed parameters

T=5	c_{11}=0.23; c_{21}=0.33; c_{31}=0.35	β=0.9
i=1, …, 3	x_{111}=4,000; x_{112}=4,500; x_{113}=4,800; x_{114}=6,000; x_{115}=7,000	γ=0.8
m=1, …, 3	$c_1^N = 3,000$; $c_1^{AD} = 5,000$; $c_1^M = 1,200$; $c_{i1}^{AG} = 1,000 \forall i$	ir=0.05
k=1		
SOI_{Cm}=0.99; SOI_{Im}=0.95; SOI_{Am}=0.97	$l_{11}^C = 34.23$; $l_{21}^C = 45.63$; $l_{31}^C = 26.62$	Φ_{C1}=0.93
BPI_1=0.4; BPI_2=0.4; BPI_3=0.2	$l_{11}^I = 20.56$; $l_{21}^I = 24.08$; $l_{31}^I = 12.67$	Φ_{I1}=0.93
	$l_{11}^A = 33.77$; $l_{21}^A = 56.90$; $l_{31}^A = 13.88$	Φ_{A1}=0.96
		α=0.9

The analyses show that in scenario I the first provider is most efficient from a cost perspective. However, if the risk perspective is considered, too, the Cloud Computing service offered by provider 3 seems to be the best-fit solution. This scenario is decisively shaped by the assumption of an inexperienced outsourcer and by the high quality and the high level of standardization of service number 3. In the second scenario the most adequate provider is the first one from a cost perspective and the third one from a risk perspective. Also, the low costs of provider 1 as well as the costs of risk factors strongly influence the result. However, in this scenario the gained experience is counterbalanced by the high values of the service importance parameters Θ_{1m}. Finally, in scenario III provider 2 is identified as the optimal solution because the overall direct costs and the risk costs are in balance; even though provider 2 is not ideal either in terms of risk or in terms of cost.

To gain a better understanding of the model mechanism and to test the robustness of the model we conducted a sensitivity analysis. This type of analysis supports the decision maker by revealing the particular impact of each adjustable parameter. For our analysis we concentrate on scenario II, since this simulation setting is a well-adjusted one in terms of parameter values and diversification of results. Instead of calculating rank correlation coefficients we decide to conduct a basic sensitivity analysis that varies the input parameters on a scale of ±10% of the default values. The objects of investigation are the values of the cost and the risk perspective as well as the overall decision costs (output variables). In Table 13 we have summarized the results of the analysis, indicating positive or negative correlations by means of arrows. On the one hand, we found that the cost part of the model shows a balanced influence of the particular parameters on the decision values. The most influential parameter is the interest rate ir which is determined by the capital market (external parameter). This strong influence is due to the fact that it is one of the last parameters included in the decision calculus. On the other hand, the risk perspective has a stronger impact on the decision calculus and the risk costs. For instance, the influence of the learning parameter α ranges from 13.32 to −11.34 with a negative correlation. Nevertheless, all factors show balanced, small values which differ from each other only slightly. The results show that the developed model can be characterized as robust by means of low fluctuating correlations. Outliers are justified by their mode of calculation.

In summary, the results of the simulation study and sensitivity analysis prove that our model is suited for practical implementation and can be adapted to real world

Table 12 Parameterization of simulation runs per scenario

Parameter	Scenario I			Scenario II			Scenario III		
n_i	0.85	0.8	0.25	0.5	0.5	0.2	0.4	0.1	0.3
o_{it}	0	0	0	2	0	1	1	3	0
Θ_{1m}	0.5	0.6	0.7	0.85	0.9	0.75	0.2	0.1	0.3
ζ_{1ij}	0.75	0.3	0.75	0.4	0.2	0.5	0.4	0.6	0.4
P_{i1}^{eu}	0.4	0.25	0.35	0.05	0.2	0.1	0.25	0.1	0.1
P_{i1}^{e+}	0.01	0.05	0.04	0.15	0.15	0.12	0.12	0.03	0.1
RA	0.8	0.95	0.4						
Costs	*156,683*	185,051	179,825	*143,705*	184,106	175,519	*139,897*	159,868	178,434
Risks	85,517	70,497	*37,945*	43,744	103,215	*30,997*	39,564	17,577	*15,723*
Overall result for i (horiz.)	242,200	255,549	*217,770*	*187,449*	287,320	206,516	179,460	*177,445*	194,158

Table 13 Effects of parameters on the decision variables by ±10% variation (in%)

Parameter	C^{O}_{ikt}	L^{O}_{ikt}	Decision calculus
n_i	[−0.17;0.17] ↑	↔	[−0.17;0.17] ↑
o_{it}	[0.33;−0.29] ↓	↔	[0.33;−0.29] ↓
Θ_{km}	[−0.24;0.24] ↑	[−1.01;1.01] ↑	[−0.39;0.39] ↑
ir	[1.47;−1.44] ↓	[1.54;−1.5] ↓	[1.49;−1.45] ↓
x_{i11}	[−2.13;2.13] ↑	[−0.18;0.18] ↑	[−1.17;1.17] ↑
β	[0.54;−0.49] ↓	↔	[0.54;−0.49] ↓
γ	[−0.4;0.4] ↑	↔	[−0.4;0.4] ↑
c^{AD}_{1}	[−0.21;0.21] ↑	↔	[−0.21;0.21] ↑
c^{N}_{1}	[−0.52;0.52] ↑	↔	[−0.52;0.52] ↑
c^{AL}_{1}	[−0.4;0.4] ↑	↔	[−0.4;0.4] ↑
c^{M}_{1}	[−0.31;0.31] ↑	↔	[−0.31;0.31] ↑
ζ_{1ij}	[−0.14;0.14] ↑	↔	[−0.14;0.14] ↑
α	↔	[13.32;−11.34] ↓	[13.32;−11.34] ↓
RA	↔	[−2.39;2.39] ↑	[−2.39;2.39] ↑
Φ_{ek}	↔	[18.72;−18.72] ↓	[18.72;−18.72] ↓
l^{e}_{ik}	↔	[−5.18;5.18] ↑	[−5.18;5.18] ↑
P^{eu}_{ik}	↔	[−2.39;2.39] ↑	[−2.39;2.39] ↑
P^{e+}_{ik}	↔	[−7.54;7.53] ↑	[−7.54;7.53] ↑

scenarios. It is fit to serve companies as an instrument for the testing of different sourcing strategies and for the identification of the most suitable Cloud Computing services. As both risks and costs are considered in the model, the most favorably priced Cloud Computing services were not always identified as the most suitable ones because the risk costs had an influence on the final result (for example in scenario III).

6 Conclusions

The model presented in this article takes a novel, quantitative cost and risk based approach to sustainable sourcing decisions regarding Cloud Computing services. The validity of the model is ensured by its consistency with established theories, practical requirements. The results of the simulation and sensitivity analysis provide this quality characteristic as well. In order to create a decision basis we converted the model elements into costs, since virtually all sourcing decisions are either directly related to or can be converted into costs (Schniederjans and Zuckweiler 2004). One major benefit of the model is its ability to identify the most suitable service for an organization with a lot more accuracy than could ever be achieved by merely calculating the direct costs. By means of configurations, decision makers can extend or reduce the core model according to their business requirements. Therefore, the model can also support new sustainable IT strategies. Further expected benefits of our model can be summarized as follows:

- improved quality of cost and risk management in IT sourcing,
- comprehensive overview of influencing factors (information structuring),
- representation of interdependencies between several types of costs and risks,
- decision makers can justify their decisions,
- risk attitudes of decision makers are accounted for,
- exploration of the sourcing decision becomes possible by modifying parameters and variables,
- decision variables become more transparent.

As illustrated above, our model can be extended to assimilate more complex scenarios, which makes it a suitable foundation for future modeling efforts and scholarly research on Cloud Computing.

As all quantitative models, our model shows some limitations that need to be taken into account (Schniederjans and Zuckweiler 2004). First and foremost, final decisions on alternatives of Cloud Computing services have to be made in view of organizational, social, psychological, political (as e. g. regulatory laws) and technological factors as well as market dynamics. However, such qualitative aspects are relatively difficult to quantify, which makes it hard to integrate them into a decision model. Our model is currently focused on cost and risk factors, and thus does not include extensive qualitative aspects that may influence IT sourcing decisions. Nevertheless, the quantitative results delivered by our model should not lead decision makers to lose sight of the long-term strategic relevance that some Cloud Computing services might have for their organization. Furthermore, some parameters cannot be exactly defined by decision makers for lack of empirical data or due to high efforts induced for the accounts department. Therefore, they are subject to estimation. However, we included several sources in the model description that provide information on how to collect data from the accounting system or how to make use of existing internal knowledge, which may either be documented already or may need to be collected by means of workshops. Additionally, we attempt to reduce the estimation effort for particular model configuration types. Despite the rigorous research process, more empirical assessments of the model are needed for an in-depth validation. In particular, the robustness of the model's results must be tested in additional settings involving different industries, customer segments, and service types (Zhu et al. 2004).

The main objective of our model is to minimize costs and risks. However, this is only one of many possible objectives that organizations usually pursue. Besides obtaining cost savings, enhanced versions of the model could focus on improvements in for instance service quality, flexibility and risk mitigation in Cloud Computing. Future research on this topic will also have to tackle some of the limitations mentioned above. For example, to ease the parameter estimation and calculation we are planning to evaluate the model by working on the basis of statistical distributions instead of sharply defined parameter values. This approach is commonly applied for quantitative models (Beimborn 2006; Harmantzis and Malek 2004). To include sophisticated approaches for risk mitigation the model needs to be greatly extended and needs to overcome the problem of mutually exclusive factors. Models of this kind are frequently constructed by means of dynamic programming methods. In order to solve them a genetic algorithm needs to be developed which compares several solutions by different individuals and evaluates their fitness to create a new "generation" of values (Silver 2004).

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Dipl.-Kfm. Benedikt Martens is a research assistant and Ph.D. student at the Research Group in Accounting and Information Systems (Prof. Dr. Frank Teuteberg) at the University of Osnabrueck. He graduated with distinction in Business Administration and Information Systems (Dipl.-Kfm.; similar to MBA) at the University of Siegen. His research interests include Cloud Computing, IT Outsourcing and Risk Management.

Prof. Dr. Frank Teuteberg Since 2007 Prof. Dr. Frank Teuteberg has been head of the Research Group in Accounting and Information Systems at the University of Osnabrueck. From 1996 to 2001 he worked as a research assistant at Europa-Universitaet Frankfurt (Oder), where he took up a postdoctoral position after his doctoral graduation in May 2001. He teaches at Virtual Global University (www.vg-u.de). Furthermore, Prof. Teuteberg is the founder and spokesman (in cooperation with Prof. Dr. Jorge Marx Gómez) of the European Research and Transfer Network for Environmental Management Information Systems (ERTEMIS; www.ertemis.net). He is the leader of a subproject on Green IS as part of the joint project “IT-for-Green” (www.it-for-green.eu) which was funded more than 2 million Euros by the European Fund for Regional Development. Prof. Teuteberg has published more than 130 scientific papers. His main research interests are Green IS, Supply Chain Management and Cloud Computing.