Decisions, Models and Opportunities in Cloud Computing Economics: A Review of Research on Pricing and Markets

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Abstract. Cloud computing has emerged as a key information technology and systems model over the last few years. Major organizations have developed and delivered cloud computing solutions and continue to do so. Consequently, a number of strides were made in the advancement of technology leading to a growth in the adoption of cloud computing. The growing recognition of cloud computing services necessitates a focus on the business aspects of cloud. However, we feel that research in this area is scant. To this effect, we performed a systematic review of cloud computing literature and reviewed 2891 abstracts and 157 articles published until the year 2012. Based on the findings of the review, we establish a framework for organising the extant research on cloud business aspects. Using the framework, we find cloud economics to be the most widely researched business aspect. In this paper, we provide a detailed review of the application of decision models in the context of cloud economics, with a specific focus on pricing and markets. The proposed framework and review results serve as a reference to IS researchers and practitioners to understand decision situations, models and opportunities.

Keywords: Cloud computing · Utility computing · Decision models · Pricing · Markets · Review

1 Introduction

In the last few decades, technical research in IS contributed a number of parallel and distributed architecture based solutions [1]. Solutions like virtualisation and web-technologies coupled with continuing growth in hardware speed, decreasing costs of processing and storage and a dramatic increase in the number of computational devices has led to commoditization of computing resources popularly known as cloud computing. Cloud computing offers infrastructure, platform and software as a service (IaaS, PaaS and SaaS), and is envisioned to be the 5th utility [3]. With this movement to commoditization and forecasts of a market of

J.G. Davis et al. (Eds.): ASSRI 2013, LNBIP 177, pp. 85–99, 2014.
DOI: 10.1007/978-3-319-07950-9_7,

size 241 billion USD [4] , ideas stemming from fields such as economics, management, and decision theory have become relevant to the new domain of computing. Research themes under economics include aspects such as pricing, markets, consumer behaviour, agent technology and so on. Studies on these aspects in particular have emerged and begun to mature. In terms of review studies, there are several works that provide review of themes pertaining to cloud. While most review works deal with taxonomy [5–10], few deal with detailed review of a specific focus area such as pricing [11] and adoption [12]. Further, most of extant research on cloud computing focuses on technology aspects and it is vital to look at economic aspects to bring in a holistic perspective to cloud computing discussions [13].

In our paper, we address these notions and specifically look into providing (1) a general classification framework for research pertaining to business features of cloud computing. (2) a detailed review of research on two streams under cloud economics namely, pricing and markets. The process of identifying the most widely researched business theme involved a systematic review of research on various business facets of cloud computing and classifying the identified research works. A review of business facets of cloud could typically benefit managers in an organizational setting and researchers in the IS space. In the course of decision making, organizations need to consider parameters relevant to the decision and use appropriate models and techniques to support their decision making. Researchers need to understand gaps, identify opportunities and address them suitably. Hence we organize our review discussion into three parts: decisions, models and research opportunities.

The organization of rest of this paper is as follows: In Sect. 2, we discuss previous literature reviews in cloud computing. In Sect. 3, we discuss the review methodology adopted in this study. In Sect. 4, we propose a classification framework and discuss in detail, two of the top researched areas under cloud economics, namely pricing and markets. In Sect. 5, we provide the implications and in Sect. 6, discuss the summary and limitations. Conclusions are presented in the last section.

2 Background

In this section, we provide a brief account of previous review studies in cloud computing and establish the motivation and the scope of our review. The following summary lists the various review studies pertaining to business and/or service aspects of cloud. Studies on technological aspects such as distributed computing frameworks and architectures, resource allocation technologies and autonomic management are beyond the scope of this paper.

2.1 Summary of Review Studies in Cloud

Literature review on business features of cloud computing are limited. Literature surveys have focused on (a) taxonomy of cloud services such as Infrastructure as a Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS)

[5,9,10], (b) classification based on technology, business, and applications [14], (c) classification based on service models and deployment modes namely public, private or hybrid [6], (d) classification based on license type, intended user group, security measures, standardization efforts and openness of cloud [11] and (e) state-of-the-art in cloud computing such as software frameworks, cloud architecture and security [15].

While, the aforementioned studies dealt with a broad morphology of cloud, few studies were specific to certain themes. Reference [11] dealt with a review of pricing models but the emphasis was on deriving a comparison across cloud and grid systems rather than the research review of cloud pricing literature. In [12], the authors provide a comparison of various cloud offerings and focus on building a decision framework but do not provide a comprehensive review of research pertinent to decision frameworks for the cloud. In [10], the authors provide a review and reference guide to Infrastructure as a Service type of cloud offering, but the focus is only on implications for e-Governance. Marston et al, provided a research agenda for business aspects of cloud [13].

An evaluation of review works on cloud indicates that (a) they lacked a systematic review approach and (b) they did not deal with decision situations/models. A review of decisions and models is critical for the following reasons: (1) It acts as a basis for researchers to learn the state-of-the art, current challenges, enhance current models and propose solutions (2) It acts as a guide for practitioners to seek and apply such models. The extant literature is scant on review of decisions and models for organizational implications of cloud computing, particularly in densely researched areas such as cloud economics. This emphasizes the need for a systematic literature review.

2.2 Scope of Our Paper

We try to seek answers for two specific questions in our review. First, we try to understand the depth of research in terms of decision situations and models encompassing various business aspects of cloud computing. Second, we provide a discussion on top two widely researched areas focusing on decisions, models and opportunities for further research.

3 Methodology and Review Statistics

We looked at review studies from cloud computing and other domains to decide our review methodology. Our review methodology is adapted from systematic procedures followed in literature and includes planning and execution stages [2,10,16]. Following Kitchenham and other review studies, research objectives were framed as part of the planning stage. The research objectives are to identify (1) The business situations where decision models are applied and (2) Models and techniques used in modelling the decisions. As part of the execution stage, primary studies for the review were collected through a four step process. In the first step, 4207 articles were collected using a set of twenty one keywords and nine bibliographic databases (refer Table 1). All papers published until the year

Table 1. Keywords and databases

Keywords	Adoption, Allocation, Auction, Behaviour, Broker, Contract, Culture, Decision, Economics, Game, Market, Negotiation, Optimization, Partnership, Policy, Pricing, Regulation, Sourcing, Scheduling, SLA, Strategy
Databases	ACM, AIS, EBSCO, Emerald, Engineering Village IEEE, Scopus, Proquest

2012 were part of the screening process. The keywords were derived through a brainstorming session among the authors and was intended to capture various business dimensions of cloud computing. In the next step 1161 duplicates, 133 non-peer reviewed 22 non-cloud computing papers were eliminated, reducing the count to 2891 articles. The third and fourth steps were designed to ensure that selected articles meet the inclusion criteria. In accordance with the research objective, the inclusion criterion is defined as the application of a decision model towards the achievement of a business objective. The decision model could vary from a simple check-list to a complex mathematical model. Few trial reviews of abstracts ensured that the authors were on a common understanding. Subsequent to the review trials, in the third step, the authors divided the resultant 2891 papers among themselves and reviewed the abstracts to ensure that the paper met the inclusion criteria. As an outcome, 2317 papers were eliminated. In the fourth and final step, a joint review was performed to strengthen the selection process, reducing the count further down to 235 articles. However, 78 of these articles were inaccessible for complete download, limiting the full review to 157 papers. Figure 1 gives a snapshot of the review methodology and step-wise statistics.

The final set of 157 papers included 43 papers from 28 journals and 114 papers from 91 conferences as of December 2012. Figures 2 and 3 gives the top five journals and top five conferences based on the number of articles chosen from those journals and conferences. The disciplines that have contributed to decision models include techniques and models from economics, finance, operations, decision science and statistics. As part of our review, we have classified the decision models found in the 157 articles into 23 categories. The 23 categories were arrived by adapting categories from Marstonś framework [13] and through an analysis of keywords from the short-listed 157 articles.The subsequent section describes the proposed classification framework.

4 Classification Framework

We developed the Classification framework by adapting the framework proposed by Marston et al. [13]. In [13], the authors had divided IS research agenda in cloud computing into five broad areas: (1) Cloud Computing economics,

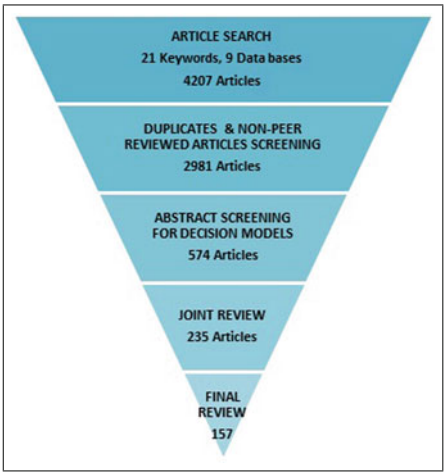

Fig. 1. Review methodology

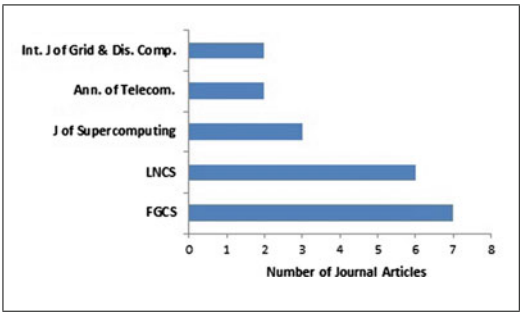

Fig. 2. Top 5 journals

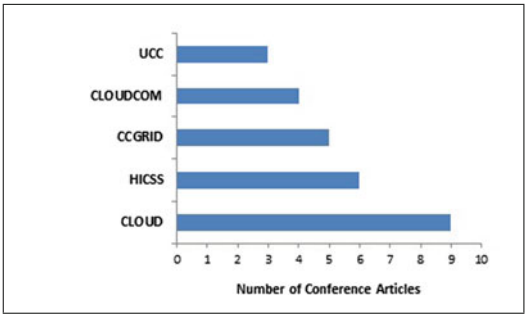

Fig. 3. Top 5 conferences

(2) Strategy research, (3) IS Policy research (4) Technology adoption and implementation research (5) Regulatory Issues. We developed this categorization further by adding sub categories. The sub-categories were essential to add a layer or resolution and map the 23 decision model categories to the five broad categories identified by Marston et al. Out of the 23 sub-categories, 12 were new and 11 were retained from Marstonś framework.

Table 2 gives an overview of Marstonś framework and sub-categories corresponding to 23 research streams. The 157 research articles were classified under 23 categories. The numbers within parenthesis in Table 2 denote the number of research papers classified in each research stream. A research paper may span across several research streams and hence could be categorised in more than one category. However, in such cases the closest classification was adopted. As the numbers indicate, Cloud economics turned out to be the widely researched area, while Pricing, Adoption, Sourcing, Market and Resource Allocation turned out to be the widely five researched streams at the sub category level. Our review will focus on the category *cloud economics* with emphasis on two of the widely research streams namely *pricing* and *markets*. Our review attempts to list (a) decision variables identified by various authors (b) summarize key works (c) research questions from the articles (d) research questions proposed by us and (e) popular techniques and models used.

4.1 Pricing

Pricing models help service providers to realise the value for services offered by them. Pricing includes setting the right tariffs and charging schemes. Review of research in pricing reveals four broad sub-themes: pricing schemes, user welfare, pricing elements and collaborative pricing. Table 3 summarizes key works in the area of pricing.

4.1.1 Decisions

Pricing Schemes: Researchers have widely studied pricing schemes such as pay-as-you-go and dynamic pricing. In [30], the authors discuss a dynamic pricing scheme suitable for allocating resources on federated clouds. In [18,19,26,35], the authors analysed dynamic pricing schemes through simulation based on real-time spot price data from a trace of Amazon EC2 spot market. In [31], the authors study the integration of currently deployed pricing schemes of real-world providers in the design of open markets. In [17], the authors propose that an optimally adjusted dynamic pricing model will outperform any pricing model with static prices. Certain studies have explored resource allocation mechanisms based on pricing. A new type of resource pricing and allocation policy proposes that users can predict resource price as well as satisfy budget and deadline constraints [34]. Bidding schemes and server allocation policies designed to optimize the average revenue earned by the SaaS provider per time unit were proposed [29]. An algorithm that takes cues from dynamic pricing and schedules the jobs/tasks in ways that the energy usage is low was developed [27]. In [33], the authors

Table 2. Classification framework

Marston's classification Broad areas	Added by authors Sub categories
Cloud economics (67)	**Pricing (32)** **Markets (17)** Sustainability (3) Agent technology (3) Brokering (4) Consumer behaviour(8)
Strategy issues in cloud (21)	Culture (1) Partnership (4) Fairness (4) Trust (9) Consumer preference (1) Consumer satisfaction (2)
IS Policy issues (48)	Interoperability (4) Sourcing (17) IT auditing (1) Security and privacy (8) Risk (10) SLA (4) Contract (4)
Technology adoption and implementation (41)	Cloud adoption (24) QoS (4) Resource allocation (13)
Regulatory (3)	Regulatory (3)

The numbers in brackets indicate the number of papers in that category

model bidding strategies for cloud resources in a dynamic pricing environment as a Prisoner Dilemma Game. [32] shows a method for pricing, developed using financial option theory where the cloud resources are treated as underlying assets to capture the realistic value of the cloud compute commodities.

User Welfare: Few authors have considered user welfare while designing or comparing pricing models. In [20], the authors propose a method to achieve social welfare in a cloud-computing environment through flat rate pricing using a congestion control approach. Another author has adopted the concept of pricing fairness from microeconomics and quantitatively analysed the impact of interference on pricing fairness [25].

Pricing Elements: Several authors have explored the elements to consider while deciding on pricing. The key elements for pricing included, hardware, maintenance, power, cooling, staff and amortization [36]. Additionally in [37], the authors have considered distribution of users, request bundle size and deadline constraints. A price update iterative algorithm, which analyses the historical utilization ratio of the resource and computes the price iteratively was developed [38]. In [21], the authors present a demand-based pricing model for maximizing

revenue of data center providers that serve clients who aim to maximize their utilities using a game formulation.

Collaborative Pricing: Researchers have also started looking at collaborative pricing schemes to suit business models where the infrastructure resources are from multiple providers. For example, each user can bid a single price value for different composite/collaborative services provided by cloud providers and similarly the collaborating providers can set a common price for the collaborative services [23]. Another approach uses genetic algorithm for pricing in cloud markets, in which a naive pricing function evolves to a pricing function that offers suitable prices in function of the system status [28].

4.1.2 Models

A review of cloud pricing literature indicates the widespread use of game theoretic and simulation based models. Game theory was used to model demand based pricing as a Stackelberg game [21,22], bidding in online cloud markets as a Prisoner's Dilemma game [33], pricing in cloud banks and under constraints as a dynamic game [24,34] and achieving strategy proof resource pricing using mechanism design [30]. Simulation models were primarily used to model fluctuations in dynamic prices [17,19] and to test/compare performance parameters [20,37]. Few authors have employed techniques like Genetic Algorithm for addressing problems such as partner selection and price negotiation [23,28].

4.1.3 Research Gaps

From Literature: [34] enquired if the mechanisms for predicting price could be generalised and opined that the delay problems associated with price predictions cannot be addressed completely. In the case of dynamic pricing schemes, [30] questions if there is a trade-off between economics and efficiency? Can the bid price be optimized based on heuristics and learning algorithms [17]? On the other hand, there is a call for research on impact of user's bid price on dynamic pricing [26]. Though few works considered cost of energy as an important element of pricing, the cases where energy price changes hourly needs to be handled [27].

Proposed by Authors: Most works reviewed in this paper, have an implicit assumption that users are rational. However, cloud users could indeed have biases and consideration of these biases could be crucial while building pricing models. In addition, researchers need to consider improvements to pricing schemes, for example, inclusion of charge-back models to protect the consumer. Few researchers have introduced and discussed pricing models like the cloud bank model but researchers need to understand the disadvantages of these models and address them.

4.2 Markets

Cloud markets provide an electronic medium for trading resources [3]. They improve efficiencies and bring geographically distributed service providers and

Table 3. Pricing studies, themes and models

Author	Decision theme				Decision technique or model
	Pricing schemes	User welfare and fairness	Price elements	Collaborative pricing	
Anandasivam and Premm [17]	x				Simulation
Andrzejak et al. [18]	x				
Ben-Yehuda et al. [19]	x	x			Simulation
Li [20]	x	x	x		Simulation
Daoud et al. [21]	x		x		Game theory
Hadji et al. [22]	x	x			Game theory
Hassan et al. [23]				x	Genetic algorithm
Li and Li [24]			x	x	Game theory
Ibrahim et al. al. [25]		x			Machine learning
Javadi et al. [26]	x				Statistical model
Li and Lo [27]	x		x		Simulation
Macias and Guitart [28]				x	Genetic algorithm
Mazzucco and Dumas [29]	x				Heuristics
Mihailescu and Teo [30]	x	x			Game theory
Roovers et al. [31]	x				
Sharma et al. [32]	x				Financial options
Sowmya and Sundarraj [33]	x	x			Game theory
Teng and Magoules [34]	x	x			Game theory
Wee [35]	x				Regression
Woitaszek and Tufo [36]			x		
Zaman and Grosu [37]			x		Simulation

consumers onto a single platform. Cloud markets help avoid vendor lock-in, empower small vendors, aid infrastructure and platform and application innovation [39,40]. Review of research in cloud markets revealed the following decision themes: collaboration, welfare, strategy and design (See Table 4). The decision theme *collaboration* focuses on how services providers partner each other in offering cloud services. While collaboration is from the perspective of the service provider, decisions involving *welfare* concern all stakeholders, namely the buyer, the seller or an intermediary. The theme *strategy* discusses the mechanisms at the disposal of the service providers operating in the market. The theme *design* focuses on the requirements of a cloud market from an economic as well as a technological perspective, which essentially provides the framework to operate.

Table 4. Market studies, themes and models

Author	Decision theme				Decision technique or model
	Welfare	Strategy	Collaboration	Design	
Hassan et al. [23]			x		Optimization
Henzinger, T.A et al. [45]	x				Simulation
Breskovic et al. [44]	x				Machine learning
Garg et al. [46]	x			x	Simulation
Goiri et al. [41]			x	x	Simulation
You et al. [47]		x			Genetic algorithm
Chen and Yeh [43]	x				Optimization
Macias and Guitart [48]		x			Simulation
Fujiwara et al. [42]	x				Optimization
Breskovic et al. [49]				x	Simulation
Niyato et al. [50]		x			Game theory

4.2.1 Decisions

Collaboration: In [23], the authors propose a combinatorial auction based collective bidding mechanism where vendors can collaborate with each other to meet user requirements while reducing conflicts, costs and negotiation time. In [41], the authors describe the profits of a cloud service provider under outsourcing and in-sourcing conditions in a federated cloud environment.

Welfare: Decisions in welfare maximization, deal with solutions that benefit a seller as well as a buyer. In [42], a double-sided combinatorial auction with an objective of maximizing welfare in forward and spot cloud markets was formulated and solved as mixed integer program. In [43], the authors design a k-pricing based market mechanism to distribute the welfare between buyer and seller. In [44], the authors recommend adoption of SLA templates in order to reduce the problem of illiquid markets and improve the welfare of resource providers and users [44]. [45] urge the cloud providers to exploit cost and time trade-offs of users and manage resource allocation in a way that improved welfare of users as well as providers.

Strategy: Cloud resource markets under monopoly, competitive and oligopolistic market conditions were analysed and optimal strategy was identified [50]. Genetic algorithm based pricing and resource allocation strategy that identify the equilibrium price and determine virtual machine allocation were found to improve the consumer's utility and service provider's profits was discussed [47]. A Negotiation based mechanism was optimized to maximize a non-additive utility function comprising various goals namely revenue maximization, client classification, non-peak utilization and reputation [48].

Design: While most literature on cloud markets pertains to economic aspects of cloud markets, few works studied the design aspects of cloud markets. Cloud

markets must be capable of handling trading requirements like use of several economic models, multiple user objectives, resource discovery and exchange requirements such as scalability, grid heterogeneity, security and fault tolerance [46]. Markets should be self-aware, have pre-defined goals, a monitoring component to track these goals, an analysis component to derive suitable action plans, a planning component to execute the actions and a knowledge component to store past histories. Metrics for self-aware markets include revenue, profits, transaction volume, costs, allocations, number of active traders, market liquidity etc. [49]. Table 3 provides a summary of key market oriented studies in literature.

4.2.2 Models

Research works across the four decision themes predominantly use simulation as a means to study the dynamics of their decision model. Simulations were used to study the effect of market based scheduling techniques [45], comparison and stress analysis of market models [46], effectiveness of market monitoring mechanisms [49], profitability in collaboration [41] and analysis of negotiation models [48]. Optimization was the next widely used methodology. In [23], the authors used an optimization approach to minimize costs in collaboration and maximize welfare in combinatorial auction based market mechanisms [42,43]. Other techniques or models include, application of Game theory to identify optimal strategies and Nash equilibrium in cloud markets [50], learning techniques in self-adapting SLA templates [44] and Genetic Algorithm in a market based resource allocation strategy [47].

4.2.3 Research Gaps

From Literature: While the need for cloud computing markets is fairly established and various market mechanisms illustrating the use of markets were proposed, the review highlights certain challenges as well. From a security and performance perspective, we need mystery shoppers, audits and a consortium to connect providers [39]. Communication and trading methodologies have to be developed for a multi-market environment [41,51]. Testing of market mechanisms have to be with real world data instead of synthetic data [23]. Market mechanisms should incorporate user behaviour and service quality expectations of the consumer [52]. From a decision modelling perspective, non-additive utility functions are yet to be developed.

Proposed by authors: The use of empirically validated functions in representing user preferences is scant. Most utility functions discussed found in the review are adhoc in nature and do not have support from behavioural research. One example is the application of decision functions from behavioural economic literature in electronic negotiations for procurement of cloud services [53].

5 Implications

This study explored in detail, several works dealing with decisions and models in cloud economics, with a focus on cloud pricing and markets. We believe that from a business perspective, this study enables a cloud consumer, vendor or a third party to readily identify parameters associated with a decision context, along with the models or techniques available to support the decision making. From a research perspective, we highlight several open questions discussed by the research community. The implications for researchers is that this study identifies opportunities where they can propose new decision contexts, new models, new parameters and improve existing methodologies. For example, through this review we found that, simulation was one of the preferred approaches in decision support. Similarly, price and cost were the parameters of choice in most of the studies reviewed. A researcher could improve a simulation approach or develop methodologies that consider parameters like reliability, trust, availability apart from cost or price.

Our study has contributed to existing body of research in cloud computing in the following ways. First, to the best of our knowledge, our study is the first systematic review and summary of decisions and models in economic aspects of cloud computing. Second,the depth of research focus and maturity on different business themes of cloud computing is presented. Third, we have collated the potential research opportunities via the research gaps section to guide researchers looking for nascent areas to work upon.

6 Summary and Limitations

In this review, we have attempted to provide a review of decisions and models in economic aspects of cloud computing. For the purpose of this article, we lay specific emphasis on two decision categories under cloud economics namely, pricing and markets. We can infer from the volume of articles (around 235) chosen from across various journals and conferences until 2012 that the general interest towards organizational implications of cloud is healthy. The fact that 67 research articles pertain to cloud economics indicates the level of importance and priority associated to this area by researchers. The top five research streams namely pricing, adoption, sourcing, resource allocation and markets account for nearly 55 % of the 157 articles reviewed. This presents an opportunity to explore and develop various models to support decision making in the less researched decision aspects like regulation, consumer behaviour, audits, contracting, agents and brokering, to name a few.

On limitations of the study, the search was restricted to nine databases and covered articles only till the year 2012. The search process did not cover books and technical reports. Further, 78 articles which were selected for the final review were inaccessible. The set of keywords used in the selection process might not exhaustively cover all decisions related to business aspects of cloud computing. The research framework in its current form does not allow classification of a paper under more than one category.

7 Conclusions and FutureWork

In this paper we provide a literature review on application of decision models to business aspects, more specifically economic aspects of cloud computing. We use a systematic research methodology to review literature and in this process reviewed 2891 abstracts and 157 completed articles. Based on the findings of our review, we propose a classification framework to organize decision making themes in cloud computing. Using this framework we review articles pertaining to the most widely researched themes under cloud economics namely pricing and markets. In general, while we find that though there were attempts to model consumer behaviour, such attempts have not been empirically supported, which in itself presents a research direction. Most studies focus on individual decision making, however the nature of cloud computing, demands for more studies involving group decision making. Studies should focus on integrating consumer behaviour with group decision making strategies.

We have provided an overview of the decisions and models applied to economic aspects of cloud computing and a framework to classify research themes. As part of future work, we would report our reviews on other widely researched areas namely adoption, resource allocation and sourcing decisions. This study has provided an empirical analysis on application of various models and techniques. We believe that study is useful to the research community in identifying potential research opportunities. From a practitioner's perspective, this research provides an overview of tools and models that apply to different decision making contexts and the parameters to consider in such contexts.

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