Optimal IT Organizational Structure: Profit Center or Cost Center

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February 12, 2012

Abstract

Some firms organize their IT departments as profit centers whereas other firms organize IT as cost centers. We study the conditions under which a cost center or a profit center structure for the IT department is optimal for the firm. Under a cost center organizational structure IT services are offered by the IT department at no charge to the consuming functional units whereas under a profit center the IT department charges the consuming unit for such services to generate a profit. We employ an economics based framework to provide novel insights into the firm's optimal organizational structure. We show that the cost center structure for IT department maximizes the firm's benefit when the marginal cost of IT is sufficiently low. Whereas prior literature has discussed higher consumption under a cost center model, we find that the profit center can generate higher consumption than the cost center. Similarly, the profit center is generally expected to deliver higher quality IT services. While this is generally true, we show that the quality of IT services can be higher under a cost center structure. Our analysis also indicates that the optimal governance structure may not always offer the widest variety of IT services. We extend the analysis to incorporate the emerging phenomenon where IT departments procure services from the cloud. We find that the adoption of cloud computing affects the optimal organizational structure. The optimal structure shifts towards the profit center when either the quality of services from the cloud is sufficiently high or the price charged by the cloud vendor is sufficiently high. Our results have several managerial implications.

Keywords: *Information Technology, IT, IT governance, Cost Center, Profit Center, Chargeback, Cloud, Cloud Computing*

1 Introduction

In 2011 Daniel Lai, the head of IT for MTR which constructs and operates the mass transit system in Hong Kong was designated a leading CIO of the year by Computerworld[1]. He noted that the IT department at MTR underwent a transformation from a cost center to a profit center to increase the value from IT to the firm. In contrast, some companies such as California based Emulex Corporation prefer the IT function to be a cost center. What drives these different choices? The lack of understanding about factors that determine optimal organizational structure is partly responsible for top executives' dissatisfaction with their IT departments. This discontent is evident in an OutSourcing Institute[2] survey that finds "out of control" or "difficult to manage" IT functions as among the top reasons for outsourcing. Research that helps firms determine the best organizational structure for the IT department may help them better control internal IT departments and increase their level of satisfaction.

The question that we analyze in this paper is whether to organize the IT function as a corporate cost center that provides free services to internal customers or as a profit center, where internal customers have to pay the IT department for IT services, which may also be referred to as a chargeback system. Given the prevalence of both organizational structures, we seek to identify key determinants that lead to the optimality of one structure over the other. Additionally, cloud computing is a rapidly growing and important source of securing IT services and we extend the analysis to determine the effect of the adoption of cloud computing on the optimal IT organizational structure. The analysis considers important attributes of corporate IT services such as marginal cost, optimal price, quality and consumption levels and variety of services offered within the context of generating benefits to the firm.

Both forms of organizing the IT department are prevalent. Examples include firms such as Proctor and Gamble and First American (Gaudin, Datamation, 2002) and the Mercator subsidiary of the Emirates Group[3] who organize their IT department as a profit center that offers a menu of IT services with corresponding prices for such services. The various entities that consume such IT services combine it with other factors to generate benefits for the firm. In contrast many other firms organize IT as a cost center that offers IT services to the consuming units at no cost. Emulex Corporation for example organizes their IT function in such a manner. Venkatraman (1997) notes that most firms organize IT departments as cost centers. A recent survey in the UK (Dunn, Techworld, 2004) indicates that 52% of the firms are organized as a profit center while the rest are cost centers. It is not clear why one form of governance is preferred over the other and what are the driving forces for such heterogeneity in the governance structure.

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[1] Computerworld Hong Kong, July/August 2011, http://edm.enterpriseinnovation.net/cw/eZine/cw0711.pdf
[2] http://www.outsourcing.com/content.asp?page=01b/articles/intelligence/oi_top_ten_survey.html
[3] www.theemiratesgroup.com

While prior literature in Information Systems does not provide an analytical model in determining the optimal governance structure, it does provide us with an understanding of the fundamental forces driving the behavior of the IT department and the IT consuming functional units under the two organizational forms. When IT is organized as a cost center, agency theory informs us that there may be excessive consumption of IT services, since it is a "free" resource. Satisfying such demand will require the outlay of the required fixed costs and marginal costs with no cost recovery. In contrast, when IT is organized as a profit center the IT consuming units will have to pay for the IT services enabling cost recovery. When IT services are priced higher than marginal cost, the consuming unit will restrain the consumption of IT services under a profit center model. Thus, there may be under-consumption in a profit center model.

A brief discussion of the marginal costs of IT services is warranted to clarify the distinction between information goods and IT services. While packaged software and digital goods are generally regarded to have zero marginal cost, corporate IT services do not fall into this category. Examples are IT services such as (a) WAN/LAN services which have cost per megabit or cost per port, (b) Smart phones which have subscription based monthly charges, (c) Storage and Backup with cost per GB or TB, (d) ERP / EDA Software licenses that typically have a fixed price component and a variable component based on the number of users and, (e) technical support which requires increasing labor costs as a step function of the demand. We simplify this characteristic by assuming a marginal cost associated with such services. Allen (1987) provides early evidence that a significant portion of IT cost is variable cost. Dewan (1996) studies pricing of computer services and suggests the marginal cost pricing approach. In this paper, we introduce quality of IT services in the context of determining the optimal organizational structure. Quality of IT services is measured by multiple attributes such as having sufficient excess capacity in networking, storage, and computing. For service and support, quality includes the timeliness of the response to bug tickets, service requests, customized reports and other metrics. Increasing the quality along such lines is costly and is related to the quantity of services consumed. For example as more users are added to a subscription based service such as smart phone services, the cost of increasing the quality of technical support increases because more labor is required for such quality improvement. Thus the marginal cost of IT services has two components, a base level of cost for providing the base service, and a cost of increasing quality. In the case of a subscription based service for smart phones, the first component would be the subscription rate for base services and other related costs such as the cost of electricity. The second component includes a quality component such as the cost of providing technical support to the desired level of responsiveness, higher value services or latency.

If the firm, represented by the CEO, was informed of the demand profile for IT services from its consuming units, the firm can generate the first best solution by determining the optimal price and quality and instruct the IT department to offer such services. However, as noted by Gurbaxani and Kemerer

(1989) when there is information asymmetry within the firm, it prevents the firm from determining the first best, value maximizing price and quality for IT services. The IT department represented by the CIO has private information about information technologies, its attributes and the potential for beneficial applications within the firm. Similarly, the consuming functional units possess private information about their demand profile and willingness-to-pay (WTP) for IT services. Therefore, there is information asymmetry between the IT department, the firm and the functional units. The firm represented by the CEO is in general neither familiar with the details of IT, nor the WTP of the functional unit. Under the profit center organizational structure, the IT department and the functional unit are motivated to exchange private information through regular interactions. Therefore, this demand information is revealed to the IT department.

The traditional options for IT services were either captive or outsourced. Most recently, cloud computing has emerged as a rapidly growing alternative for securing IT services. As a viable, growing alternative to captive IT services, cloud computing is subject to governance and management issues and is therefore relevant to any current and future study on the management and control of IT. According to Gartner[4], CIOs are adopting cloud computing faster than anticipated and it is at the top of the CIOs' technology priorities. Hence it is important for us to consider the effect of the adoption of cloud computing on the choice of organizational structure.

IT governance literature

We now provide an overview of the literature on the question of profit center versus cost center. Sharpe (1969) examines the economics of computers after the advent of large scale computing in the 1970s and suggests that the structure should be based on maximizing firm value. He notes that the concept of a profit center is key to internal pricing but also considers cases where the profit center compromises overall firm benefit. Olson and Ives (1982) analyze the two governance structures empirically and find that there is more user involvement when chargeback (pricing) is employed. Gurbaxani and Kemerer (1988) consider information asymmetry and employ agency theory to suggest that IT departments or consuming units act as self-interested parties. In a related paper, Gurbaxani and Kemerer (1989) propose the application of agency theory to the management of information systems and specifically address the cost center versus profit center debate. They suggest that under a profit center structure the monopoly market power of the IT department may result in constraining the quantity of IT services below levels that are optimal for the firm. On the cost center side, they make note of the problem of controlling IT costs since the consuming business unit does not incur usage costs. Venkatraman (1997), suggests a value center concept for IT as a means to overcome the weaknesses of traditional structures

[4] Gartner: Cloud Computing Services, Virtualization Top CIO 2011 Wish Lists, by Andrew R Hickey, CRN 10:45 AM EST Mon. Jan. 24, 2011

such as the cost center and profit center.

We now provide a review of associated literature that primarily analyzes the profit center approach. Olson and Chervany (1980) while analyzing centralization, raise the question of charging for information services and note that it is a complex decision. Through a survey, Bergeron (1986) found that user accountability and user authority were enhanced by chargeback systems, and users regulate their usage and control expenses if pricing is present. Allen (1987) favors a profit center approach to ensure prudent consumption of IT services and also notes that the primary obstacle to imposing a profit center is the notion that all IT costs are fixed. He provides support for the argument that IT costs are not fixed and that a significant portion is a variable cost component. Ellig (1993) offers a discussion of the issues related to pricing for internal corporate services and argues for the judicious use of internal markets. Vitale and Beath (1999) discuss the effects of chargeback from discussions with firms in a variety of industries and find that IT chargeback has an impact on usage and has a small impact on performance. Several researchers have focused on the truthful demand revelation or the free rider problem. Based on a process discovered by Groves (1973) and Clarke (1971), Pick and Whinston (1989) propose an internal pricing mechanism for IT services within a firm that is truth revealing. Under this pricing scheme, rational agents will state their preferences truthfully and the free rider problem may be eliminated.

Other aspects of IT governance include the location of decision rights and environmental factors such as competition and markets. There is the multiple contingency view offered by Sambamurthy and Zmud (1999) and the locus of IT decision view described by Peter Weill and Richard Woodham (2002), where IT decision making authority is desired to be located with the information necessary for making that decision. Gu, Xue and Ray (2008) empirically show that firm performance is positively related to the IT governance alignment. Xue, Ray and Gu (2011) show a curvilinear relationship between environmental uncertainty and IT infrastructure governance. The locus of decision rights view has an embedded assumption that there is a unique locus and it is not spread among hierarchies and across organizational facets. Vithayathil (2011) offers an information asymmetry view of IT governance and proposes testable hypotheses for relating IT governance to firm performance.

Cloud computing is a burgeoning option for sourcing IT services and is being rapidly adopted for IT infrastructure as well as higher level IT services. Cloud computing has a profound impact on the nature of the cost structure of IT services. Given this impact, we believe that cloud computing will affect the optimal organizational structure. Therefore, this paper considers the effect of the adoption of cloud computing on the question of profit center versus cost center. Armbrust et. al. (2009, 2010) and Mell et.al. (2011) provide the structure and characteristics of cloud computing and note that cloud computing consists of software applications offered as a service as well as computing and storage infrastructure services. Thus, Software as a Service (SaaS) is a cloud based IT service. An example of a SaaS vendor is salesforce.com while an example of cloud storage and computing infrastructure is Amazon's EC2. A key benefit to users of cloud services is the pay-as-you-use attribute. A second important financial feature enabled by cloud computing as noted by Armbrust et. al. is the ability for the firm to eliminate the fixed cost of a captive datacenter and only incur usage-based pricing for IT services from the external cloud vendor.

While prior literature describes the implications of a cost center versus a profit center and examines some of the behavioral and organizational consequences of charging for IT services, it does not consider marginal cost, quality and variety of IT services and their relationship to the organizational structure. As noted earlier, many corporate IT service components have non-zero marginal cost that should be accounted for in determining the organizational structure. These costs are described in more detail earlier in this section on page 2.

This paper considers two organizational governance structures for the IT department: a cost center and a profit center, and develops an analytical model to examine the factors that determine the optimal structure. The analysis is extended to the context of cloud computing. We show that the nature of the cost function is a factor in determining the optimal IT organizational structure. We find that each organizational structure provides advantages and disadvantages so that the profit center and cost center approaches should both exist depending on the nature of the firm. We show that the cost center model is optimal when the marginal cost and the fixed cost of quality are low; otherwise the profit center model is optimal. Whereas prior literature has discussed excess consumption under a cost center model, in contrast, we find that the profit center can generate higher consumption of IT services. This occurs when the quality offered by the profit center is much greater than the cost center's quality. Furthermore, the quality that maximizes benefits for the firm in a cost center can be greater than the quality chosen by the IT department in the profit center model. This occurs when consumption under the cost center model is much greater so that the fixed cost can be spread over a larger unit demand. Counter-intuitively, we show that the optimal organizational structure may not always offer the most variety of IT services – there exists a region where the profit center model is optimal but the cost center model may deliver greater variety of IT services.

The impact of cloud computing on the choice of organizational model has not been studied previously. We extend the model to include quality and price from a cloud vendor, and show that the adoption of cloud computing affects the optimal organizational model for IT. When the cloud vendor's pricing power is high, the adoption of cloud computing will make it optimal for some firms to shift from the cost center model to the profit center model. The quality offered by the cloud vendor also affects the choice of organizational structure. Higher quality from the cloud vendor will favor a profit center organizational structure.

The rest of the paper is organized as follows: §2 develops the conceptual model while §3 develops and analyzes a general model without a functional form for demand, §4 develops and analyzes the model with a linear demand function. §4.3 and §4.4 analyzes the two organizational structures and their effect on quality of IT services, consumption, and variety. §5 analyzes the impact of cloud computing on the choice of organizational structure. §6 is a discussion of the results and, §7 concludes.

2 Model

In this paper we target one important issue relating to the organization and pricing of internal IT services. The structure of the internal IT department impacts the quality, quantity, cost and benefits derived from IT services. Hence the focus of this paper is the question of optimal organizational structure of the IT function. We develop a stylized model to compare the benefits of organizing IT as a cost center or as a profit center.

2.1 Conceptual model of IT organizational structure

Our model considers three players, namely: (i) the IT department, which provides a given number of services to functional units, (ii) the functional unit which is a consumer of IT services (for tractability and ease of exposition, the functional units within the firm that consume IT services are abstracted into a single monolithic functional unit) and, (iii) the firm as a whole. The firm can select one of two IT organizational structures: (a) a cost center where the IT department offers services at zero price and at a prescribed quality level decided by the firm or, (b) a profit center where the IT department decides the price and quality level of IT services offered to the functional unit.

The first structure is a cost center as described in figure 1a below. In this structure, IT services are provided at zero prices to the functional units. The benefit to the firm from IT is determined by the surplus generated by the functional unit from the consumption of IT services. The IT department incurs cost for providing such services. The firm is the decision maker for the quality level and variety of IT services to be offered by the IT department. The functional unit determines the amount of IT services to consume based on its demand function.

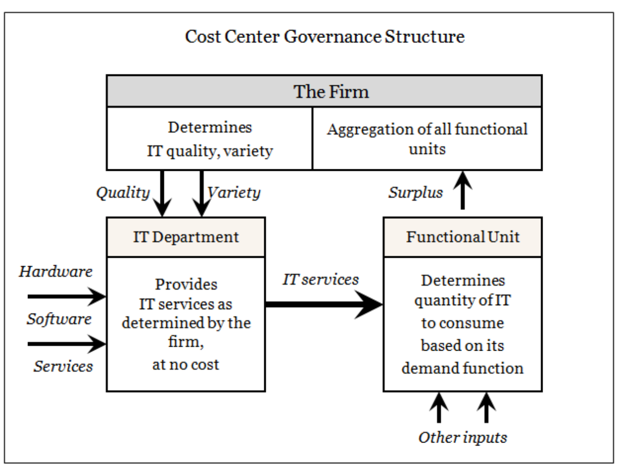

Figure 1a the cost center model

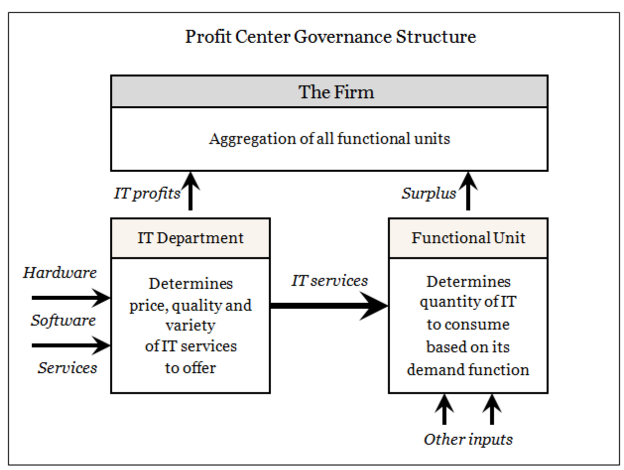

Figure 1b the profit center model

The second structure is a profit center as depicted in figure 1b above (also referred to as chargeback in the literature). Here, (a) the IT department decides the price, quality and variety of IT services to offer based on maximizing its profit, (b) the IT consuming functional unit determines the quantity of IT services it will consume based on its demand function and generates a surplus from the consumption of IT services, (c) the benefit to the firm is the sum of the IT department profit and the functional unit surplus. We focus only on those services that the firm offers through its internal IT department, therefore in this model, functional units must obtain IT services from the IT department We examine the case of outsourced services from the cloud in §5.

The conceptual model incorporates information asymmetry with respect to demand for IT services from the functional unit. Demand information or the willingness-to-pay (WTP) for IT services is of interest to the entity that has the authority to set price and quality. This demand function is known to the functional unit since it is the consumer of IT services. Under a cost center, this information remains private to the consuming functional unit. Under a profit center the IT department is able to learn this demand function because of the ability to price its services and observe corresponding demand from the functional unit.

3 General model

We develop a stylized model that simplifies many issues to focus on key economic parameters for reasons of tractability and exposition. As discussed in §2.1, the model considers three players, namely: (1) the IT department, (2) the functional unit that is a consumer of IT services and, (3) the firm as a whole. The first player, the IT department provides x quantity of services at a quality level q to the functional unit. Such services have a cost consisting of a non-negative marginal cost $c \cdot q$ which depends on the cost parameter c and the quality level q for each unit of service, and a convex fixed cost of quality denoted by $g(q)$. Therefore, the total cost of IT services can be expressed as:

$$C_{IT} = x \cdot (c \cdot q) + g(q) \tag{1}$$

Under a cost center model, the IT department is directed by the firm to offer a certain quality q^{CC} which is exogenously determined[5]. As described in §1, page 2, information asymmetry between the firm and the functional unit prevents the firm from computing optimal quality q^{*CC}. However, as a benchmark, we examine the case when $q^{CC} = q^{*CC}$. In contrast, under a profit center model, the IT department is

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[5] Note that consistent with prior literature, the firm does not have access to the private information of the consuming functional unit and therefore cannot optimize q^{CC}. In practice, firms typically set q^{CC} through external benchmarking. See for example Gordon (1994).

informed of the demand function and can therefore determine its optimal price denoted by the non-negative variable p^{*PC} and its optimal quality denoted by q^{*PC}.

As discussed in §1, page 2, the marginal cost parameter c of IT services is strictly positive such as in Smartphone services where the firm pays a regular subscription price. Costs that depend on equilibrium quantity of IT services such as technical support labor, bandwidth costs, and subscription services are treated as marginal cost. As noted by Oi (1962) labor has a variable component although it may be a step function. Therefore we treat a portion of IT labor such as the CIO and other management personnel as fixed costs, while other components such as technical and other staff levels required to provide the equilibrium quantity of IT services (while maintaining quality) as variable costs. The fixed cost of quality $g(q)$ is a separate component that is increasing in the quality level of IT services offered. A simple illustration is that a very high level of redundancy in storage, computing, or networking will require additional capital for multiple backup systems or failover systems.

The second player, the functional unit that consumes IT services has a demand function $D(p,q)$ that determines its consumption schedule based on price and quality levels offered by the IT department:

$$x = D\left(p,q\right) \tag{2}$$

Therefore, for each price and quality there is an optimal quantity that maximizes the functional unit surplus. The inverse demand function with respect to quantity for a given quality level, denoted by $D^{-1}\left(D\left(p,q\right),q\right)$, provides the willingness-to-pay (WTP) for IT services by the consuming functional unit. We integrate the WTP function to determine the surplus of the consuming unit:

$$S_U = \int_0^{D(p,q)} \left(D^{-1}\left(x,q\right)\right) dx - \left(D^{-1}\left(D\left(p,q\right),q\right) D\left(p,q\right)\right) \tag{3}$$

The third player is the firm which is an aggregation of the functional unit and the IT department. The firm determines the optimal organizational structure that maximizes the benefit to the firm from IT services.

Assumptions

A1. Regularity conditions: Standard mathematical regularity conditions are assumed. The demand, cost and profit functions are continuous, and the payoff functions are twice differentiable. Demand is increasing in quality and decreasing in price: $\frac{\partial D}{\partial q} = D_q\left(p,q\right) > 0$, $\frac{\partial D}{\partial p} = D_p\left(p,q\right) < 0$. The cost of quality is increasing in quality: $\frac{dg}{dq} = g_q(q) > 0$, $\frac{d^2 g}{dq^2} = g_{qq}(q) > 0$. Therefore, the cost function is convex. The IT profit and firm value are evaluated net of IT cost and are concave functions. The inverse demand function $D^{-1}\left(D\left(p,q\right),q\right)$ exists and $\frac{\partial D^{-1}}{\partial q}=D_q^{-1}\left(x,q\right)>0$.

A2. Zero consumption price: For each quality level, there is a threshold of maximum consumption denoted by $D\left(0,q\right)$ when price is zero. Similarly, at a sufficiently high price denoted by $D^{-1}\left(0,q\right)$ there will be no consumption of IT services.

Variables and parameters employed are summarized in table 1 below.

Symbol	Description
p	price of IT services
$p^{*PC}=D^{-1}\left(D\left(p^{*PC},q^{*PC}\right),q^{*PC}\right)$	optimal price for IT services under profit center
x	quantity of IT service consumed by functional unit
q	quality of IT service
q^{*CC} q^{*PC}	optimal quality of IT services under cost center optimal quality of IT services under profit center
c	marginal cost parameter of IT services
$D\left(p,q\right)$	demand profile for IT services of the functional unit
$D^{-1}\left(D\left(p,q\right),q\right)$	willingness-to-pay (WTP) for IT services at a given quantity and quality, by the functional unit

Table 1: list of model variables, functions and parameters

3.1 Cost center IT organizational structure

Under the cost center model, the internal IT consuming functional unit does not pay for IT services which are treated as a corporate overhead. The sequence of steps is as follows: (1) the firm directs the IT department to offer a certain level of quality and, (2) the IT consuming functional unit determines the quantity of IT services demanded. The net benefit to the firm is the surplus generated by the consuming unit (from IT services) less the cost of IT and is expressed as follows:

$$S_f=\int_0^{D(0,q)}\left(D^{-1}\left(x,q\right)\right)dx-C_{IT}=\int_0^{D(0,q)}\left(D^{-1}\left(D\left(p,q\right),q\right)\right)dx-D\left(p,q\right)cq-g(q)\ .$$

PROPOSITION 1: IT as a cost center

a) Information asymmetry case: The optimal benefit from IT to the firm is as follows:

$$S_f^{CC}=D\left(0,q^{CC}\right)\left(D^{-1}\left(0,q^{CC}\right)-c\cdot q^{CC}\right)-g_q(q^{CC})+\int_0^{D^{-1}\left(0,q^{CC}\right)}D\left(p,q^{CC}\right)dp$$

b) Benchmark case with no information asymmetry: The optimal benefit from IT to the firm is as follows:

$$S_f^{*CC} = D\left(0, q^{*CC}\right)\left(D^{-1}\left(0, q^{*CC}\right) - c \cdot q^{*CC}\right) - g(q^{*CC}) + \int_0^{D^{-1}\left(0, q^{*CC}\right)} D\left(p, q^{*CC}\right) dp \cdot$$

The benchmark case denotes the maximum possible benefit to the firm from a cost center model. The expression for the firm benefit comprises of the surplus to the IT consuming functional unit less the total cost of IT. The total cost of IT at the optimal quality is the sum of marginal cost for the optimal quantity of IT services demanded and fixed cost of quality. For the purpose of comparing the cost center model to the profit center model, we use the benchmark case scenario for the cost center.

LEMMA 1: Equilibrium consumption

Under a cost center organizational structure, the following relationship will hold for quantity of IT services consumed at the optimal price and optimal quality:

$$D\left(0, q\right)\Big|_{q^{*CC}} = \left(\left(\int_0^{D(0,q)} D_q^{-1}\left(x, q\right) dx - c \cdot q \cdot D_q\left(0, q\right) - g_q(q)\right) / c\right)\Bigg|_{q^{*PC}} .$$

Lemma 1 shows that the factors that drive optimal consumption levels under a cost center are: (i) functional unit surplus given by $\int_0^{D(0,q)} D^{-1}\left(x, q\right) dx$, (ii) the marginal cost increase from the increase in consumption from a unit increase in quality determined by $c \cdot q \cdot D_q\left(0, q\right)$ and, (iii) marginal fixed cost of quality $g_q(q)$.

3.2 Profit center IT organizational structure

Under the profit center organizational structure, the IT department is vested with the authority to charge a price and set the quality level for IT services to the consuming functional unit. As mentioned in section 2, this paper focuses on internal IT services and does not address the issue of whether it is optimal to outsource certain IT services. Both the functional unit as well as the IT department generate surplus for the firm. The sequence of moves is as follows: (1) the IT department learns the demand preference of the IT consuming functional unit and offers IT services at a price and quality denoted as $\left\{p^{*PC}, q^{*PC}\right\}$ and generates a profit $S_{IT} = \left(x^{*PC} \cdot p^{*PC}\right) - C_{IT}$, and (2) the IT consuming functional unit determines the quantity x^{*PC} demanded based on the price and quality provided by the IT department. The benefit generated to firm from IT is the sum of the surplus generated by the functional unit S_U and the profits generated by the IT department S_{IT}. The cost of providing IT services (as noted in §3.1) is $C_{IT} = x \cdot \left(c \cdot q\right) + g(q)$. The firm's benefit from IT is expressed as: $S_f = S_U + S_{IT}$. Since price and quality is determined by the IT department, its optimization problem is $\underset{p,q}{Max}\{S_{IT}\}$. The IT department's optimization leads to the proposition that follows.

PROPOSITION 2: Equilibrium for IT as a profit center

Under a profit center organizational structure, the optimal price p^{*PC} quality q^{*PC} that the IT department will offer is determined by the solution to the following first order conditions:
$\begin{bmatrix} D_q(p,q)/D(p,q) \\ D_p(p,q)/D(p,q) \end{bmatrix}(p-c\cdot q)=\begin{bmatrix} (g_q(q)/D(p,q))+c \\ -1 \end{bmatrix}$*. The optimal benefit from IT to the firm is as follows:*

$$S_f^{*PC}=\left(\int_0^{D(p^{*PC},q^{*PC})} D^{-1}\left(D\left(p^{*PC},q^{*PC}\right),q^{*PC}\right)dx\right)-\left(D\left(p^{*PC},q^{*PC}\right)\cdot c\cdot q^{*PC}+g(q^{*PC})\right).$$

The solution to the first order condition in proposition 2 specifies the optimal price and quality of IT services that the IT department will offer under a profit center structure. For ease of interpretation, the first order conditions for the profit center may be rewritten as $\begin{bmatrix} \partial x \\ \partial x \end{bmatrix}\left(p_{PC}^*-c\cdot q_{PC}^*\right)=\begin{bmatrix} \partial g+c\cdot x\cdot\partial q \\ -x\cdot\partial p \end{bmatrix}$. The first term on the left hand side ∂x is the change in consumption for a unit increase in quality or price. In the case of price, this will be a decrease in consumption. The second term on the left hand side $\left(p_{PC}^*-c\cdot q_{PC}^*\right)$ is the profit for each unit of IT service consumed or unit margin. Therefore, the left hand side represents the net change in margin. The expression $(\partial g+c\cdot x\cdot\partial q)$ on the right hand side represents the marginal fixed cost of quality and the marginal cost from the increase in consumption from higher quality. With respect to price, the right hand side expression $(-x\cdot\partial p)$ represents the marginal cost from decreased consumption due to the increase in price. Therefore it is now readily seen that the first order conditions that generate the optimal quality and price are in terms of unit margin and the marginal cost from change in consumption.

LEMMA 2: Effect of change in quality on quantity consumed

Under a profit center organizational structure, the following relationship will hold at the optimal price and optimal quality: $\left.\frac{D_q(p,q)}{D_p(p,q)}\right|_{p^{*PC},q^{*PC}}=-\left(\left.\frac{g_q(q)}{D(p,q)}\right|_{q^{*PC}}+c\right).$

Lemma 2 shows that the ratio of marginal quantity consumed when quality is increased compared to the marginal quantity consumed when price is increased is equal to the sum of the marginal cost and the unit marginal cost of quality. The intuition behind this relationship is that (a) quality increase has an opposing effect when compared to price increase in terms of consumption and, (b) at the equilibrium price and quality any increase in price must be offset by a corresponding decrease in quality and the relationship is determined by the total unit marginal cost.

LEMMA 3: IT consumption under profit center

Under a profit center organizational structure, the following relationship will hold for quantity of IT services consumed at the optimal price and optimal quality:

$$D(p,q)\Big|_{p^{*PC},q^{*PC}} = \left(\frac{(p - c \cdot q)\big(D_q(p,q) - D_p(p,q)\big) - g_q(q)}{(1+c)} \right)\Bigg|_{p^{*PC},q^{*PC}} .$$

Proposition 3 shows that three factors can drive optimal consumption under a profit center to higher levels: (i) high unit margin which is given by $(p - c \cdot q)$, (ii) high levels of marginal effect on consumption determined by the non-negative term $(D_q(p,q) - D_p(p,q))$, noting that $D_p(p,q) < 0$, and (iii) an increase in fixed cost of quality determined by $g_q(q)$.

3.3 Comparison of profit center and cost center organizational models

The results from propositions 1 and 2 can be used to generate a comparison between the two organizational structures in order to determine the effect of marginal cost on the choice of optimal structure and the effect on consumption of IT services. The comparison leads to the following proposition:

PROPOSITION 3: Marginal cost and choice of organizational structure

The profit center organizational structure is optimal when the following condition for marginal cost and fixed cost of quality holds:

$$c > \frac{\left(\int_0^{D(0,q^{*CC})} D^{-1}(x, q^{*CC})dx - \int_0^{D(p^{*PC},q^{*PC})} D^{-1}(x, q^{*PC})dx \right)}{\left(D(0,q^{*CC})q^{*CC} - D(p^{*PC},q^{*PC}) \cdot q^{*PC}\right)} + \left(g(q^{*PC}) - g(q^{*CC})\right) .$$

The threshold for marginal cost stated in proposition 3 is a necessary condition for the profit center to be superior to the cost center organizational structure. The numerator of the first term on the right-hand-side is the difference in functional unit surplus between the cost center and profit center. The denominator of the first term is the difference in the product of quality level q and quantity consumed. We can interpret this as the total quality $q \cdot D(p,q)$. The right hand side also includes the second term which is the difference in the fixed cost of quality between the profit center and the cost center.

PROPOSITION 4: Equilibrium consumption of IT services

The profit center organizational structure generates higher consumption of IT services when the following condition for marginal cost holds: $\frac{c}{1+c} > \frac{\left.\left((p-c\cdot q)\left(D_q(p,q)-D_p(p,q)\right)-g_q(q)\right)\right|_{p^{*PC},q^{*PC}}}{\left.\left(\int_0^{D(0,q)} D_q^{-1}(x,q)dx - c\cdot q\cdot D_q(0,q)-g_q(q)\right)\right|_{q^{*PC}}}$.

The threshold for marginal cost stated in proposition 4, an implicit inequality, is a necessary condition for the profit center to generate higher consumption of IT services than the cost center. The numerator contains the price cost margin $(p-c\cdot q)$ times the difference in the marginal effect of quality and price on demand $\left(D_q(p,q)-D_p(p,q)\right)$, less the marginal fixed cost of quality $g_q(q)$. Therefore, the numerator is the net marginal increase in IT profit. The denominator is the marginal increase in functional unit surplus less the marginal cost of quality from the change in quantity, which is the net marginal increases in surplus for the functional unit. The right hand side of the inequality is therefore the marginal increase in IT profit for a unit marginal increase in functional unit surplus.

4 Linear demand model

This section considers a linear functional form for the internal demand for IT services to determine the equilibrium solutions and to develop additional results that are unavailable from the general model. There is precedence for the use of a linear demand form. This functional form has been used in prior literature as in Dixit (1979) and also in Banker et. al. (1998), Gal-Or (1985), Gal-Or and Ghose (2005), Vives (1983), and Singh and Vives (1984). The following demand function is employed in order to analyze the impact of the organizational structure on (i) quality, (ii) consumption or quantity, (iii) variety, and (iv) the impact of cloud computing.

$$x = k - \alpha\cdot p + \beta\cdot q \qquad (4)$$

This linear demand is used in conjunction with marginal cost $(c+q)$, and a convex fixed cost of quality denoted by $(a\cdot q^2)$. The parameter c is the marginal cost independent of quality while the parameter a is half the marginal fixed cost of quality. Therefore, the cost of IT services is expressed as:

$$C_{IT} = x\cdot(c+q)+a\cdot q^2 \qquad (5)$$

Note that for simplicity and ease of exposition quality is normalized to zero such that the minimum acceptable quality is $q=0$. The boundary solutions are available in the attached appendix 1.

The intercept of the demand function is denoted by k. The inverse demand function $p = (k + \beta \cdot q - x)/\alpha$ provides the willingness-to-pay (WTP) for IT services by the consuming functional unit. We integrate WTP to determine the surplus of the consuming unit:

$$S_U = \left(\int_0^q ((k + \beta \cdot q - x)/\alpha) dx \right) - (p \cdot x) \tag{6}$$

Variables and parameters employed are summarized in table 2 below.

Symbol	Description
p	price for IT services
x	quantity of IT service consumed by functional unit
q	quality of IT service
c	marginal cost of IT services
a	fixed cost of quality of IT services parameter
F	fixed cost of IT services independent of quality
α	marginal disutility to functional unit from price of IT service
β	marginal value of quality of IT service to functional unit
k	intercept: quantity consumed at zero price and base quality

Table 2: List of variable and parameters under the linear demand model

The two IT organizational models of a cost center and a profit center are analyzed in the following sections. Each structure is analyzed separately and the results are compared and relevant propositions are reported. A first best case where the firm has the necessary information to determine optimal quality and price is presented in the attached appendix 1.

4.1 IT as a cost center

The internal IT consuming functional unit does not pay for IT services which are treated as a corporate overhead. The sequence of steps is the same as in section § 3.1. The benefit to the firm from IT is the surplus generated by the IT consuming functional unit less the cost of IT and is expressed as follows: $S_f = \left(\int_0^{(k+\beta \cdot q)} \frac{(k + \beta \cdot q - x)}{\alpha} dx \right) - \left(x \cdot (c + q) + a \cdot q^2 + F \right)$.

PROPOSITION 5: Equilibrium interior solution for cost center

Under a cost center organizational structure; (i) The quantity consumed by the functional unit is $x^{*CC} = \frac{\alpha(2a \cdot k + \beta \cdot (k - c \cdot \beta))}{2a \cdot \alpha + \beta \cdot (2\alpha - \beta)}$, *(ii) the surplus generated by the functional unit is*

$S_U^{*CC} = \frac{\alpha \cdot \left(2a \cdot k + \beta \cdot (k - c \cdot \beta)\right)^2}{2\left(\beta \cdot (\beta - 2\alpha) - 2a \cdot \alpha\right)^2}$ *and, (iii) The benefit to the firm from IT is*

$S_f^{*CC} = \frac{2a \cdot k \cdot (k - 2c \cdot \alpha) + \alpha \cdot (k - c \cdot \beta)^2}{2\left(2a \cdot \alpha + \beta \cdot (2\alpha - \beta)\right)} - F$ *and, (iv) The optimal quality offered by the firm is*

$q^{*CC} = \frac{k \cdot (\beta - \alpha) + c \cdot \alpha \cdot \beta}{2a \cdot \alpha + \beta \cdot (2\alpha - \beta)}$. *An interior solution requires the following:* $a > \beta \cdot (\beta - 2\alpha) / 2a$ *for concavity and* $\beta > k \cdot \alpha / (k - c \cdot \alpha)$ *for non-negative quality, and* $c < k \cdot (2a + \beta) / \beta^2$ *for non-negative quantity.*

Proposition 5 reports the optimal quality that the firm would offer under a cost center organizational structure. Since price is zero under this organizational model the functional unit will have no deadweight loss at the given quality level since it will consume the maximum quantity under its demand function. However this leads to inefficient consumption as users who value the services below marginal cost will continue to consume them. This inefficient consumption is more salient when the cost of the services is high. Thus there is lower motivation to improve quality. From the expression for the optimal quality we can observe that a high marginal effect of price (α) relative to the marginal effect of quality (β) will serve to reduce optimal quality. The proof is in the attached appendix 1.

4.2 IT as a profit center

The setup of the profit center model and the sequence of steps is as reported in section § 3.2. The IT department generates a profit $S_{IT} = \left(x^{*PC} \cdot p^{*PC}\right) - C_{IT}$, and the surplus generated by the functional unit is S_U. The benefit to the firm is $S_f = S_U + S_{IT}$. The cost of providing IT services is as noted in §4: $C_{IT} = x \cdot (c + q) + a \cdot q^2$. Since price and quality is determined by the IT department, its optimization problem is $\underset{p,q}{Max}\{S_{IT}\}$. The IT department's optimization leads to the following proposition.

PROPOSITION 6: Equilibrium solution for profit center

Under a profit center organizational structure; (i) The optimal quality offered by the firm is $q^{*PC} = (k - c \cdot \alpha) \cdot (\beta - \alpha) / \left(4a \cdot \alpha - (\alpha - \beta)^2\right)$, *(ii) The optimal price is* $p^{*PC} = 2a \cdot (k + c \cdot \alpha) + (\alpha - \beta) \cdot (c \cdot \beta - k) / \left(4a \cdot \alpha - (\alpha - \beta)^2\right)$, *(iii) The quantity consumed by the functional unit is* $x^{*PC} = 2a \cdot \alpha \cdot (k - c \cdot \alpha) / \left(4a \cdot \alpha - (\alpha - \beta)^2\right)$, *generating a surplus of*

$S_U^{*PC} = 2a^2 \cdot \alpha \cdot (k - c \cdot \alpha)^2 / \left(4a \cdot \alpha - (\alpha - \beta)^2\right)^2$ *, (iv) The IT department's profit is*

$S_{IT}^{*PC} = a \cdot (k - c \cdot \alpha)^2 / \left(4a \cdot \alpha - (\alpha - \beta)^2\right) - F$ *and , (v) The benefit to the firm from IT is*

$S_f^{*PC} = a \cdot (k - c \cdot \alpha)^2 \cdot \left(6a \cdot \alpha - (\alpha - \beta)^2\right) / \left((\alpha - \beta)^2 - 4a \cdot \alpha\right)^2 - F$. *An interior solution requires the following:*

$a > (\alpha - \beta)^2 / 4\alpha$ *for concavity,* $\alpha < Min\left\{\frac{k}{c}, \frac{\beta}{c}\right\}$ *for non-negative quality and quantity, and*

$a > (\beta - \alpha) \cdot (c \cdot \beta - k) / 2(k + c \cdot \alpha)$ *for non-negative price.*

Proposition 6 reports the optimal price and quality that the IT department will offer under a profit center structure. The optimal quality and price are non-negative in the interior. Since the price for IT services is greater than the marginal cost of providing the services, there will be some deadweight loss and consequently consumption will be less than efficient. Since the IT department can recover cost through pricing, it is better motivated to improve quality than a cost center in most cases. The proof is in the attached appendix 1.

4.3 Comparison of cost center versus profit center organizational structures

In this section, we compare the two organizational structures to analyze the differences and understand the conditions when one structure may be preferred over the other. The firm determines the choice of the organizational model for the IT department based on net benefit to the firm from IT services.

PROPOSITION 7: The optimal IT organizational model

The cost center is the optimal organizational structure if and only if the marginal cost is sufficiently low,

$c < \left(Z + 2\sqrt{2a^3k^2\alpha \cdot \left((\alpha - \beta)^2 - 4a \cdot \alpha\right)^2 \left(2a \cdot \alpha + \beta \cdot (2\alpha - \beta)\right)} \right) / X$ *, where*

$X \equiv (24a^3\alpha^3 - 2a \cdot \alpha \cdot (2\alpha - 5\beta) \cdot (\alpha - \beta)^2 \beta - (\alpha - \beta)^4 \beta^2 - 4a^2\alpha^2 \cdot (\alpha^2 - 8\alpha\beta + 8\beta^2))$ *and*

$Z \equiv k(-8a^3\alpha^2 + 4a^2\alpha^2 \cdot (3\alpha - 4\beta) - 2a \cdot \alpha \cdot (\alpha - 4\beta)(\alpha - \beta)^2 - (\alpha - \beta)^4 \beta)$,

The optimal organizational structure for the IT department depends on a number of factors including marginal cost, fixed cost, taste for quality, demand intercept and price elasticity of demand. We show the impact of the firm's preference for quality in figure 2b. Proposition 7 examines another important variable – the marginal cost c. It shows that there is a crossover point in the preferred organizational structure based on marginal cost and fixed cost of quality since the expression for the threshold contains the fixed cost of quality parameter a and marginal cost c. When the IT department is organized as a cost center, IT services are offered at zero price to the IT consuming functional unit and these services are consumed even when the marginal cost exceeds the benefit to the firm from increased consumption. Such excessive consumption lowers the benefits to the firm from IT. This inefficiency hurts the cost center when the marginal cost is sufficiently high, enabling the profit center model to dominate.

On the other hand, the IT department charges a price under the profit center model that can unduly stifle demand from the IT consuming unit. When the marginal cost for IT services are low, the inefficiency from under-consumption in a profit center model dominates the loss from excessive consumption in a cost center model. Therefore when marginal cost is sufficiently low, the cost center model dominates. The proof is in the attached appendix 1. The crossover in proposition 7 is illustrated in figure 2a below. As a corollary, figure 2b shows that firms that value quality differently will come to different conclusions about the optimal organizational structure. Specifically, firms that have a high value for quality are more likely to employ profit center organizational model whereas other firms are more likely to adopt the cost center model. Therefore, our results should not be interpreted to indicate the global optimality of either organizational model – rather it depends on the nature of the firm and its business in terms of marginal cost and the value of quality of IT services to the business.

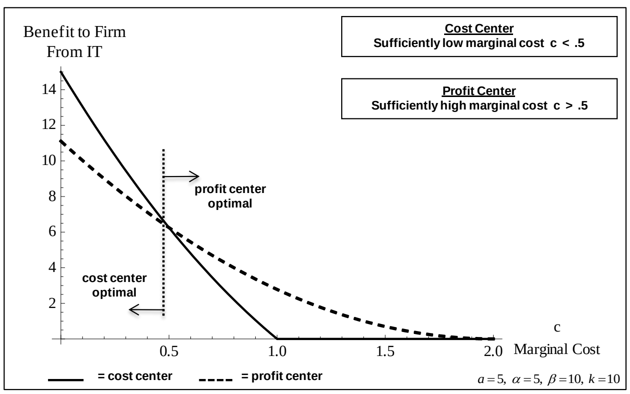

Figure 2a:

Optimal IT organizational and marginal cost

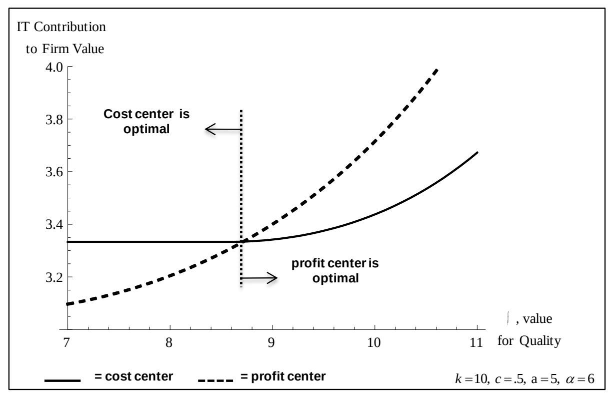

Figure 2b:

Optimal IT organizational and quality

PROPOSITION 8: Comparison of optimal quality between organizational structures

The cost center organizational structure generates a higher interior optimal quality offering of IT services if and only if the demand intercept is sufficiently high,

$k > c\cdot\alpha\left(2a(\beta+\alpha)-\beta(\beta-\alpha)\right)/(2a-\alpha)(\beta-\alpha)$ *and* $\alpha > \beta\cdot(\beta-2a)/(2a+\beta)$ *and* $a < \beta/2$.

Proposition 8 is counter-intuitive in that one would expect the cost center to offer lower quality since this organizational model provides IT services at no charge leading to over-consumption. When the cost center increases quality, the consumption of IT services increase and so does the cost of such services. Together, these forces drive up the efficiency loss from a cost center model. The cost center responds by limiting costly consumption via lower quality. While this is true under most circumstances, proposition 8 highlights an interesting region where this result is reversed. We show that the quality that maximizes benefits for the firm in a cost center can be greater than the quality chosen by the IT department in the profit center model. This occurs when high levels of consumption under the cost center model enable the fixed cost of quality to be spread over the larger quantity demanded. This is reflected in the condition stated in Proposition 8 where the intercept k of the demand function is required to be sufficiently high to yield this result. Figure 3a illustrates the proposition. The proof is in the attached appendix 1.

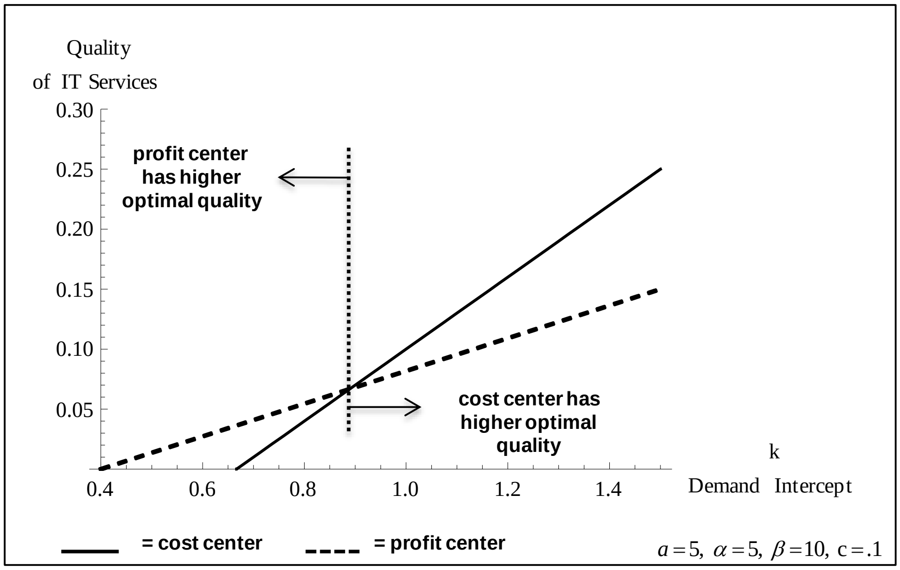

Figure 3a: Difference in optimal quality between profit center and cost center

PROPOSITION 9: Comparison of consumption of IT services

The profit center organizational structure generates higher consumption of IT services in the interior when fixed cost of quality is bounded, $\left((\alpha-\beta)^2/4\alpha\right)<a<A$, *and* $\beta<k/c$, *where*

$$A=\frac{c\cdot\alpha\cdot\beta\cdot(3\beta-2\alpha)-k\cdot\alpha(2\beta-\alpha)+\sqrt{\alpha\cdot\begin{pmatrix}k^2\alpha^3+2k\cdot\alpha\cdot\beta^2\cdot(c\cdot\alpha-2k)+\\4\beta^3(k-c\cdot\alpha)(k+c\cdot\alpha)+c\cdot\beta^4\cdot(5c\cdot\alpha-4k)\end{pmatrix}}}{4\alpha(k+c\cdot\alpha)}$$

Gurbaxani and Kemerer (1989) use an agency based framework to make the argument that the cost center will lead to excessive consumption when IT services are provided at no charge to the user. Thus we expect consumption of IT services to be greater under a cost center model relative to the profit center model. We find that this result is true in most settings; however proposition 9 identifies an interesting region where these results are reversed. Proposition 9 shows that the profit center structure enables higher consumption of IT services by the functional unit when compared to the cost center model when the fixed cost of quality is within a certain range. Intuitively, one can understand this result by extending proposition 8 which shows that the optimal quality under a profit center model can be much greater than the optimal quality under a cost center model. When this quality gap strongly favors the profit center, there is more demand under the profit center model despite the negative impact of price because the services are far more valuable due to their higher quality than the lower quality services provided by the cost center. Figure 3b illustrates the proposition. The proof is in the attached appendix 1.

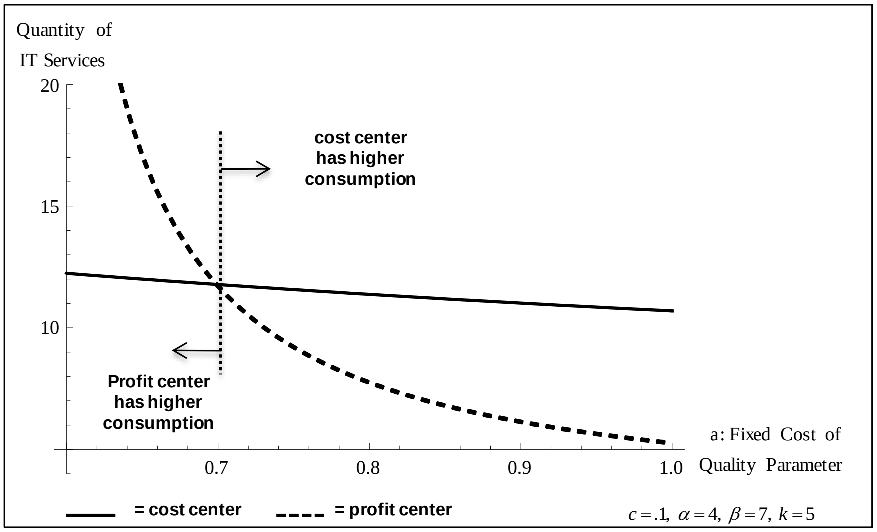

Figure 3b: Difference in consumption of IT services between profit center and cost center

PROPOSITION 10: Comparison of functional unit surplus

The surplus of the IT consuming functional unit is maximized under the cost center organizational structure when the quality of IT services offered is sufficiently high,

$$q^{*CC} > \left(k\cdot(\alpha-\beta)^2 - 2a\cdot\alpha\cdot(k+c\cdot\alpha)\right)/\left(4a\cdot\alpha-\beta\cdot(\alpha-\beta)^2\right).$$

Proposition 10 is a natural follow-on to proposition 5 and generates the conditions from the countervailing forces of quality and price. Under the cost center structure, there is no deadweight loss on the preference curve of the functional unit when the optimal cost center quality is offered. Under the profit center structure, IT services are mostly offered and consumed at higher quality than the cost center. The result in proposition 10 occurs when the cost center quality is sufficiently high such that the cost of increasing quality under a profit center structure is greater than the increase in surplus offered by the cost center. The net effect is that the cost center structure's ability to eliminate deadweight loss is superior in terms of surplus for the consuming unit when this quality threshold is met. Therefore, above this quality threshold, the internal IT consuming functional unit will prefer the cost center organizational structure. The proof is in the attached appendix 1.

4.4 The effect of organizational structure on variety of IT services

As noted in §2.1, this paper introduces a novel feature of variety of IT services built on the argument that each IT service offering has a fixed cost associated with it. Up to this point we have assumed that the IT department provides a given number of services. In this section, we examine which organizational structure offers a greater number of services if the number of services were to be determined endogenously. Service i has fixed cost $h_i(.)$ and IT services are assumed to be ordered such that $h_i(.) < h_{i+1}(.)$. All services are symmetric in terms of marginal costs and demand.

In a profit center model the IT department determines whether a service is offered or not offered. The IT department will offer a service if it provides a positive contribution to the IT department's profit. Hence, the number of services offered by the IT department is the count of services that provide a positive contribution. In contrast, the cost center offers a service if there is a positive net benefit to the firm. The organizational model that provides greater total benefit to the firm (sum of net benefit from each service) is the optimal organizational structure for the IT department.

PROPOSITION 11: Impact of organizational structure on variety of IT services

The cost center will offer a wider variety of services when the marginal cost is sufficiently low $c < \left(A + 2\sqrt{a^2k^2 \cdot \left(4a\cdot\alpha - (\alpha-\beta)^2\right)\left(2a\cdot\alpha + \beta\cdot(2\alpha-\beta)\right)} \right) / B$, *where* $A = k\cdot\beta(\alpha-\beta)^2 - 2a\cdot k\cdot\alpha\left(2(a+\beta)-\alpha\right)$, *and* $B = 2a\cdot\alpha\left(2\alpha(a+1)-3\beta\right) + \left(\beta(\alpha-\beta)\right)^2$. *Otherwise, the profit center offers a wider variety of services.*

Under the profit center organizational model, the IT department makes IT related decisions, hence the decision to offer the next service is based on IT profits. Whereas, under the cost center model, the decision to offer the marginal service is based on the overall benefit to the firm.

As shown in figure 4, we find that the organizational model that is optimal also offers the larger number of services in most cases. Region A in figure 4 is interesting because in this region the profit center is optimal for the firm, yet the cost-center offers a larger number of services. This result can be understood by examining the IT department's profit and the firm's benefit from the marginal service. When the profit center model is optimal, the firm's benefit from the profit center model is greater than that from the cost center. However, under the profit center model the IT department decides whether or not to offer the marginal service. The IT department will not offer the service if the marginal profit from that service is negative. The IT department's profit is one component in the firm's benefit and since the IT departments profit will be lower under the new service, it will not offer this new service even when offering this service leads to increased benefit for the firm. In contrast the firm makes the decision in the cost center model and maximizes firm benefit. Therefore, a region can exist where the IT department generates a smaller profit than the firm benefit under a cost center. As a result the cost center has the ability to incur additional fixed cost for the new service and remain non-negative in net benefit to the firm when compared to the IT department which has lower ability to incur such fixed cost. Therefore, even though the profit center is optimal in this region, the cost center will offer a wider variety of IT services. Figure 4 below illustrates proposition 11. The proof is in the attached appendix 1.

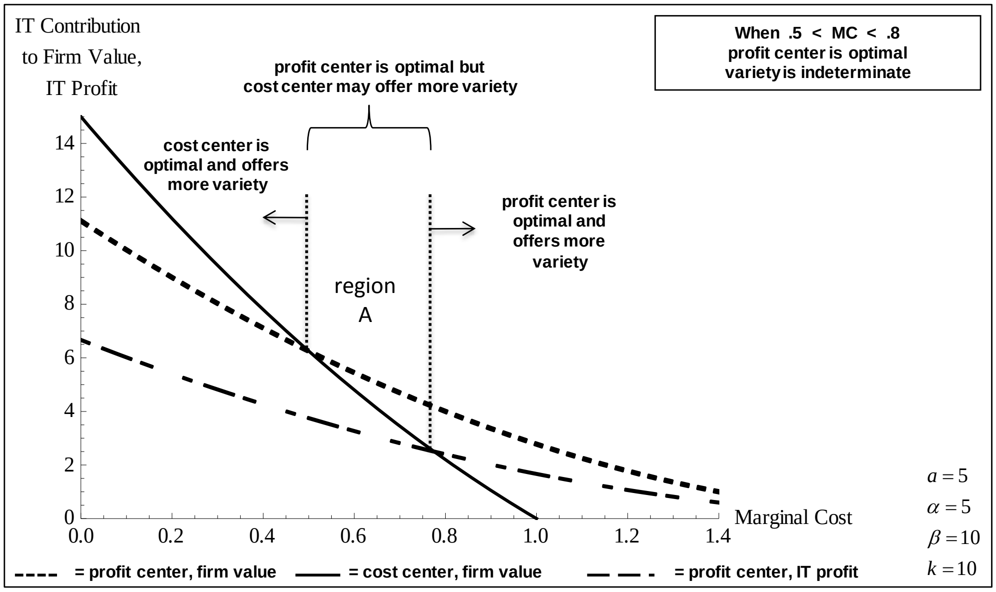

Figure 4: Comparison of service variety between profit center and cost center

5 The effect of cloud computing

Cloud computing has rapidly emerged as a viable option for many IT services and the options. International Data Corporation (IDC, 2008) predicts a compounded annual growth rate of 27% in cloud services vs. a 5% growth in on-premise IT between 2008 and 2012. Accordingly, we extend our work on the choice of IT organizational structure to consider the effect of the adoption of cloud computing. We will show that this important technological trend will have an effect on the optimal organizational structure for the IT department.

5.1 Cloud computing model

The IT department or the firm can source basic IT services from a cloud vendor and the IT department adds value by providing vendor selection, monitoring and improving quality of IT services. The cloud vendor incurs the necessary fixed cost for providing services and charges the firm a usage based price.

The cloud vendor may have multiple clients and the cloud vendor will determine its price and quality based on the overall market demand for its services, the cost of providing the service and the cost of quality. We assume that the cloud vendor’s optimization including its price and quality are exogenous because they are determined by the larger market for its services rather than the demand from the focal firm. We denote the cloud vendor's quality as q_C. The price charged by the cloud vendor depends on the quality of their service and various other factors such as, competition, efficiencies from multi-tenancy, scale and scope. We introduce a parameter $\theta > 0$ to map the net effect of vendor’s quality to its price. The price charged by the cloud vendor $p_C = c + \theta \cdot q_C$. Larger values of θ represent increasing pricing power of the cloud vendor. $\theta = 1$ represents a market environment where the price charged by the cloud vendor is equal to the marginal cost of delivering the same quality of service internally. The marginal cost to the firm is the unit price charged by the external cloud vendor (p_C).

The IT department procures cloud based IT services and adds value to these services by monitoring the vendors and improving the quality levels of these services. The IT department determines the amount of value added services to provide to the internal IT consuming department by endogenously optimizing the quality level q that is delivered. The fixed cost of quality incurred by the IT department is a function of the improvement in quality delivered by the IT department and is expressed as $a \cdot \left(q^2 - q_C^2\right)$

PROPOSITION 12: Interior solution with cloud computing

(a) Under a cost center organizational structure with cloud computing the benefit to the firm is

$$S_{fC}^{*CC} = \left(2a \cdot \left(\begin{array}{l} 2a \cdot \alpha \cdot q_C^2 + k^2 + q_C^2 \cdot \beta \cdot (2\alpha - \beta) - \\ 2k \cdot \alpha \cdot \left(c + q_C \cdot (\theta - 1)\right) \end{array} \right) + \alpha \cdot \left(k - \beta \cdot \left(c + q_C \cdot (\theta - 1)\right)\right)^2 \right) / \, 2a \cdot \alpha + \beta \cdot (2\alpha - \beta)$$

, and the optimal quality offered by the IT department is $q_C^{*CC} = \dfrac{k \cdot (\beta - \alpha) - \alpha \cdot \beta \cdot \left(c + q_C (\theta - 1)\right)}{2a \cdot \alpha + \beta \cdot (2\alpha - \beta)}$.

(b) Under a profit center organizational structure with cloud computing, (i) The optimal price of IT services by the IT department is $p_C^{*PC} = \dfrac{2a \cdot \left(k + \alpha \cdot \left(c + q_C \cdot (\theta - 1)\right)\right) + (\beta - \alpha)\left(k - \beta\left(c + q_C \cdot (\theta - 1)\right)\right)}{4a \cdot \alpha - (\alpha - \beta)^2}$*, (ii) The optimal quality offered by the IT department is* $q_C^{*PC} = \dfrac{(\beta - \alpha)\left(k - \alpha \cdot \left(c + q_C (\theta - 1)\right)\right)}{4a \cdot \alpha - (\alpha - \beta)^2}$ *and, (iii) The benefit to the firm is*

$$S_{fC}^{*PC} = a \cdot \left(\begin{array}{l} (k - c \cdot \alpha)^2 \left(6a \cdot \alpha - (\alpha - \beta)^2\right) + 2q_C \cdot \alpha \cdot (k - c\alpha)\left((\alpha - \beta)^2 - 6a \cdot \alpha\right)(\theta - 1) \\ + q_C^2 \cdot \left(\begin{array}{l} 16a^2\alpha^2 - (\alpha - \beta)^2 \left(\beta + \alpha(\theta - 2)\right)(\alpha \cdot \theta - \beta) + \\ 2a \cdot \alpha \cdot \left(8\alpha \cdot \beta - 4\beta^2 + \alpha^2 \left(3\theta(\theta - 2) - 1\right)\right) \end{array} \right) \end{array} \right) / \left((\alpha - \beta)^2 - 4a \cdot \alpha\right)^2.$$

Proposition 12 reports the optimal price and quality that the IT department will offer when cloud computing is adopted. The benefit to the firm from IT depends on the pricing power θ of the cloud vendor and the exogenous quality q_C offered by the cloud vendor. The cloud vendor's price and quality will vary depending on the aggregate demand faced by the vendor, level of competition and scale and scope efficiencies that the cloud vendor may enjoy. The proof is in the attached appendix 1.

PROPOSITION 13: Comparative Statics for vendor's quality and pricing power

(a) With the adoption of cloud computing the optimal organizational structure is the profit center when the cloud vendor's quality is sufficiently high:

$$q_C > \frac{\left(A\cdot(1-\theta)+2\sqrt{2}\sqrt{a^3k^2\alpha\left((\alpha-\beta)^2-4a\alpha\right)^2\left(2a\alpha+(2\alpha-\beta)\beta\right)(\theta-1)^2}\right)}{B\cdot(\theta-1)^2}, \textit{ where}$$

$$A=\begin{pmatrix} 8a^3\alpha^2(k+3c\cdot\alpha)+(\alpha-\beta)^4\beta(k-c\cdot\beta)-2a\cdot\alpha(\alpha-\beta)^2 \\ (k\cdot(4\beta-\alpha)+c\cdot\beta\cdot(2\alpha-5\beta)) \\ -4a^2\alpha^2\left(\alpha\cdot(3k+c\alpha)-4\beta\cdot(k+2c\alpha)+8c\cdot\beta^2\right) \end{pmatrix} \textit{ and } B=\begin{pmatrix} 24a^3\alpha^3-2a\cdot\alpha\cdot(2\alpha-5\beta)(\alpha-\beta)^2\beta- \\ (\alpha-\beta)^4\beta^2-4a^2\alpha^2\left(\alpha^2-8\alpha\beta+8\beta^2\right) \end{pmatrix}$$

(b) With the adoption of cloud computing the optimal organizational structure is the profit center when the cloud vendor's pricing power is sufficiently high:

$$\theta > \left(2\sqrt{2}\sqrt{a^3k^2q_C^2\alpha\cdot\left((\alpha-\beta)^2-4a\alpha\right)^2\left(2a\cdot\alpha+(2\alpha-\beta)\cdot\beta\right)}+q_C\cdot A\right)/\,q_C^2\cdot B, \textit{ where}$$

$$A=\begin{pmatrix} -8a^3\alpha^2\left(k+3(c-q_C)\cdot\alpha\right)-(\alpha-\beta)^4\beta\cdot\left(k+\beta(q_C-c)\right) \\ +2a\cdot\alpha\cdot(\alpha-\beta)^2\left(\beta(c-q_C)(2\alpha-5\beta)-k(\alpha-4\beta)\right)+ \\ 4a^2\alpha^2\left(k\cdot(3\alpha-4\beta)+(c-q_C)\left(\alpha^2-8\alpha\cdot\beta+8\beta^2\right)\right) \end{pmatrix} \textit{ and } B=\begin{pmatrix} 24a^3\alpha^3-2a\cdot\alpha\cdot(2\alpha-5\beta)(\alpha-\beta)^2\cdot\beta \\ -(\alpha-\beta)^4\beta^2-4a^2\alpha^2\left(\alpha^2-8\alpha\cdot\beta+8\beta^2\right) \end{pmatrix}.$$

Proposition 13 demonstrates that the adoption of cloud computing affects the optimal organizational structure. The magnitude and direction of this effect is determined by the cloud vendor's quality and pricing power. When the cloud vendor offers sufficiently low quality the increased fixed cost incurred to improve quality is defrayed over a higher consumption level under the cost center model. When quality from the cloud vendor is sufficiently high, the IT department is not burdened with a high fixed cost of quality and there is sufficient consumption of IT services under pricing to favor the profit center model. When the cloud vendor's pricing power is sufficiently low, relatively inexpensive cloud services coupled with the reduced fixed cost favors the cost center since excess consumption is not sufficiently costly to deter the cost center. When the pricing power of the cloud vendor is sufficiently high, it is necessary to limit consumption by invoking the profit center model. The proof is in the attached appendix 1. Figure 5 illustrates the effect of the cloud vendor' s quality and pricing power on the organizational structure.

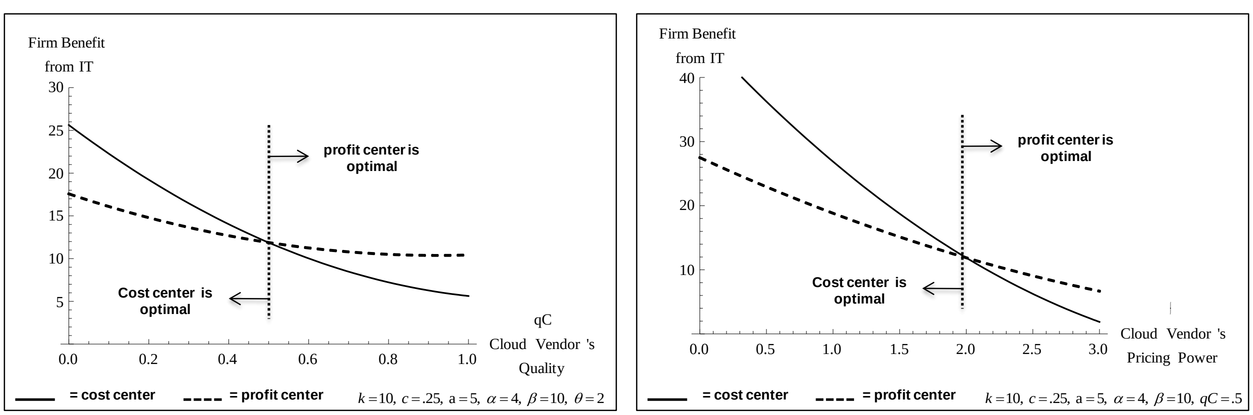

Figure 5: Effect of cloud computing quality and price on optimal organizational structure

Additionally, figure 6 below illustrates three comparisons on each chart. The first is the difference in firm benefit from IT services between the cloud computing based profit center and the captive profit center. The second comparison is the similar difference between the cost center with cloud computing and the captive cost center. The third curve is the difference-in-difference between the profit center and the cost center. The first plot in figure 6 shows these differences in firm benefit against the cloud vendor's pricing power. The profit center is preferred under cloud computing when compared to the captive IT alternative. In similar vein the cost center is preferred under cloud computing when compared to the captive IT alternative provided the cloud vendor's pricing power is sufficiently low. The difference-in-difference curve shows that the profit center is less impacted by the cloud when the cloud vendor's pricing power is sufficiently low. Higher pricing power above this threshold impacts the cost center less than the profit center and therefore, favors the profit center under cloud computing when compared to the captive IT alternative.

The second plot in figure 6 shows that for the given parameter set, both organizational models are preferred under captive IT services. The difference-in difference curve shows that the impact of cloud computing under this parameter set favors the profit center when compared to the captive IT alternative. Together, the charts in figure 6 serve to illustrate our finding that the adoption of cloud computing affects the choice of organizational model for the IT department.

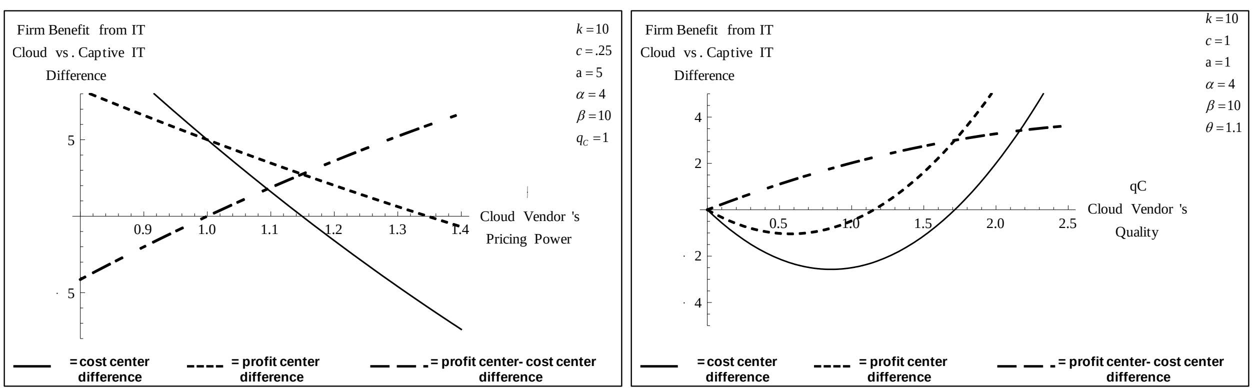

Figure 6: Difference in IT benefits to firm between cloud computing and captive IT

6 Discussion

Our paper provides a model and framework that considers an important question regarding the structure of the IT organization and its implications. The question of whether the IT function should be organized as a cost-center or as a profit center has been discussed by scholars and practitioners. An analytical model is developed to compare the performance of the two organizational schemes and to identify conditions that are suited for each scheme. The analysis includes characteristics such as quality, quantity and variety of IT services under the alternative organizational structures. §5 extends the analysis to consider the effect of the adoption of cloud computing on the choice of IT organizational structure.

Results and contributions

This paper offers several insights and findings that are novel and counter-intuitive with respect to prior literature. While prior literature describes the implications of a cost center versus a profit center and examines some of the behavioral and organizational consequences of charging for IT services, it does not consider marginal cost, quality and variety of IT services and their relationship to the organizational structure.

We start with a comparison of the equilibrium solutions for the benefit to the firm from IT services under the cost center model and the profit center model. As described in §1, many corporate IT services such as smart phone or tablet based services come with a monthly subscription cost and have material marginal cost. While Gurbaxani and Kemerer (1989), and Sharpe (1969) consider marginal cost as a factor in setting price under a profit center, its impact on the optimality of the IT organizational structure has not been analyzed in prior literature. A new contribution from this paper is that high marginal cost for IT services drives the optimal structure to a profit center and low marginal cost drives the optimal structure to a cost center.

Comparative statics are analyzed under the cost center organizational structure and the profit center structure to understand the effect of organizational structure on quality of IT services, the quantity of IT services consumed and the variety of the offering of IT services. We introduce quality of IT services as a factor in the decision making process on organizational structure. First, we find that the endogenously determined quality of IT services can be higher under either organizational structure. This is counter-intuitive because Allen (1987) notes that one of the major advantages of the profit center structure is its ability to provide better services because the IT department finds it beneficial to improve quality over that of a cost center organizational structure. While we find that this is often true, however, higher consumption by the cost center can enable the fixed cost of offering higher quality IT services to be defrayed over this larger base of users. This can sometimes facilitate higher quality of IT services under the cost center.

Second, we show that the notion from prior literature that “free” IT services drive higher consumption under the cost center model does not always hold. Gurbaxani and Kemerer (1989) point out that a cost center leads to overconsumption and waste. While this paper lends analytical support to this propensity in most cases, we find that there are conditions when the profit center model has higher consumption of IT services when compared to the cost center model. This can be explained by examining the quality differential between the profit center and the cost center. When this differential is sufficiently large, it drives higher consumption of IT services by the functional units under the cost center model.

Third, we extend our analysis to consider how the variety of IT services offered is impacted by the organizational structure. The results show that the choice of organizational structure impacts the number of IT services offered. In most cases the optimal organizational structure will offer a larger variety of IT services. However, when the profit center is optimal, sometimes the cost center offers a larger variety of IT services. To understand this result, note that the profits of the IT department under the profit center are lower than the benefit to the firm under the cost center. Therefore the marginal benefit of an additional service to the firm under the cost center model can be positive even when the marginal benefit to the IT department under the optimal profit center is negative.

We now state the results from extending the model to incorporate cloud computing. The analysis of the model under cloud computing shows that higher levels of quality from the cloud vendor or strong pricing power of the cloud vendor will favor a shift from the cost center model to the profit center model. This can be understood by noting the role of cloud computing in converting the fixed costs of IT services into marginal cost for the firm. This result is consistent with the captive IT model as shown in proposition 7 where higher marginal cost favors the profit center. Furthermore, high pricing power or high quality by the cloud vendor favors the profit center under cloud computing when compared to the captive IT alternative.

Managerial implications

Our analysis indicates that managers need to consider the organizational model as an important decision factor in organizing and managing the IT department to ensure maximum benefits to the firm from the use of IT. Managers should take into account the cost structure and the demand characteristics of the consuming units in determining the choice of organizational structure for the IT department. A firm operating in a business that relies on high level of face-to-face interactions may only need basic undifferentiated IT services such as networking, email, financial and organizational reporting, with minimal value-added services. Such an IT department is likely to offer services with low marginal costs and low fixed costs and therefore be best served by a cost center organizational model.

In contrast a firm that is in the global market for consumer products with a customer base that is heterogeneous in taste and geography may need sophisticated analytical and supply chain IT software and services along with real-time inventory, demand prediction for new products and real-time customer service support. Such a firm is likely to have a high value for the quality of IT services which may be measured by the sophistication and accuracy of the tools and the level of real-time support. This firm will be better served with the profit center organizational model for the IT department.

Rapid change is an inherent characteristic of IT and there are competing forces that impact cost of IT services to a firm. Innovation in new products and services enable IT vendors to increase prices while Moore's law has been relentlessly driving costs and prices down in computing, storage and communications. Based on our analysis, firms may need to consider a transition in the organization structure of the IT department when faced with significant change in the cost of IT. A change such as the shift from mainframes to client server with the advent of low cost distributed computing may have required some firms to shift from a profit center to a cost center. Today, we are witnessing the emergence of ubiquitous mobile computing with low cost personal devices, with low to high priced subscription services. In this scenario, some firms with a cost center organizational structure may need to consider a profit center structure.

Cloud computing has emerged as a rapidly growing alternative source of IT services. Managers will need to consider a potential change in the organizational structure of the IT department with the adoption of cloud computing. Managers in a firm with a cost center organizational structure that is moving from captive IT services to cloud-based IT service will need to consider a transition to a profit center when the cloud vendor has high pricing power or high quality in the form of value added services. In contrast, when the cloud based services are characterized by low cost and low value added such as in pure storage or computing, such a transition may not be necessary. Infrastructure or platform services from the cloud are likely to be more competitively priced and may favor a cost center whereas higher value added services such as CRM may favor a profit center as they are likely to enjoy increased pricing power and generate more value to the firm from higher quality. As an example a firm operating with the IT department as a cost center that limits its usage to infrastructure services with the procurement of basic storage, computing and networking capability may require no transition in the organizational structure of the IT department. However, if the same firm chooses to secure higher priced and higher value-added services under SaaS with some degree of customization through Application Programming Interfaces (APIs), a transition from a cost center to a profit center may be necessary to maximize benefits to the firm from IT.

7 Conclusion

This paper provides an analysis of the question – when and under what conditions is it optimal for IT to be organized as a profit center or a cost center. Both organizational models are in use. A stylized model is employed to undertake the analysis using an economics based approach. While the model makes many simplifying assumptions both for tractability as well as for exposition, it produces a rich set of results regarding the impact of IT cost, quality and the adoption of cloud computing on the choice of organizational structure. Clearly any abstraction that is necessary for an analytical model is limited in its ability to encompass all the nuances of a complex subject such as IT governance. Future work can relax some of the assumptions, for example, we assumed internal IT departments charge monopoly prices. However, in practice firms may use cost recovery pricing or other forms of regulated pricing using external benchmarks or industry practices. In such cases the qualitative results developed in this paper will hold since it does not change the underlying forces. The thresholds that determine the optimal organizational structure will shift.

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Optimal IT Organizational Structure: Profit Center or Cost Center

Appendix 1

Additional propositions, lemmas & proofs

Linear demand - first best case

As noted in page 4 if there is no information asymmetry the first best maximizes the firm benefit as follows as follows: $S_f = \left(\int_0^{(k-\alpha p+\beta q)} \frac{(k+\beta q - x)}{\alpha} dx \right) - \left(x(c+q) + aq^2 + F \right)$

Linear demand - first best equilibrium solution; no information asymmetry

Under the first best case; (i) The optimal quality offered by the firm should be $q^{*FB} = k(k-c\alpha)(\beta-\alpha)/\left(2a\alpha-(\alpha-\beta)^2\right)$, *(ii) The optimal price of IT should be* $p^{*FB} = \left(2ac\alpha + (\alpha-\beta)(c\beta-k)\right)/\left(2a\alpha-(\beta-c\alpha)^2\right)$, *(iii) The quantity consumed by the functional unit is* $x^{*FB} = 2a\alpha(k-c\alpha)/\left(2a\alpha-(\alpha-\beta)^2\right)$, *generating a surplus of* $S_U^{*FB} = \left(2a\alpha(k-ca)\left(a(k+c\alpha)+(\beta-\alpha)(k-c\beta)\right)\right)/\left((\alpha-\beta)^2-2a\alpha\right)^2$, *(iv) The IT profit is* $S_{IT}^{*} = -a(k-c\alpha)^2(\alpha-\beta)^2/\left((\alpha-\beta)^2-2a\alpha\right)^2$ *and , (v) The firm value is* $S_f^{*FB} = a(k-c\alpha)^2/\left(2a\alpha-(\alpha-\beta)^2\right)-F$.

By construction, this is the best case for the firm and both the cost center and the profit center are suboptimal in the sense that they generate lower firm value.

Proof of first best equilibrium solution under linear demand

The total surplus available for the consuming business unit is as follows:

$$S_U = \int_0^{(k-\alpha p+\beta q)} \frac{(k+\beta q-x)}{\alpha} dx - xp = \left((k-\alpha p+\beta q)^2/2\alpha\right) - xp \tag{1}$$

The profit from IT services is:

$$S_{IT} = x(p-cq) - aq^2 - F \tag{2}$$

The net firm value generated is:

$$S_f = \left((k-\alpha p+\beta q)^2/2\alpha\right) - (k-\alpha p+\beta q)cq - aq^2 - F \tag{3}$$

The firm's problem and first order condition is as follows

$$\underset{q,p}{Max}\left\{\left((k-\alpha p+\beta q)^2/2\alpha\right) - (k-\alpha p+\beta q)cq - aq^2 - F\right\} \tag{4}$$

$$\left(2aq\alpha + c\alpha(k-\alpha p+2\beta q) + \beta(k+q\beta)\right)/\alpha = 0, \quad cq\alpha - p\alpha = 0 \tag{5}$$

The first order conditions are readily solved to obtain the first best optimal quality and price.

$$q^{*FB} = k(\beta - c\alpha)/\left(2a\alpha - (\beta - c\alpha)^2\right), \qquad p^{*FB} = ck(\beta - c\alpha)/\left(2a\alpha - (\beta - c\alpha)^2\right) \tag{6}$$

Substituting the optimal price and quality into the firm value expression (3), the IT profit expression (2) and the functional unit surplus expression (1), the demand function $(k - \alpha p + \beta q)$ and simplifying, we obtain the required results

$$\begin{aligned} S_f^{*FB} &= ak^2/\left(2a\alpha - (\beta - c\alpha)^2\right) - F, \qquad & S_{IT}^{*} &= -ak^2(\beta - c\alpha)^2/\left(-2a\alpha + (\beta - c\alpha)^2\right)^2 \\ S_U^{*FB} &= 2a^2k^2\alpha/\left(-2a\alpha + (\beta - c\alpha)^2\right)^2, \qquad & x^{*FB} &= 2ak\alpha/\left(2a\alpha - (\beta - c\alpha)^2\right) \end{aligned} \tag{7}$$

Proof of proposition 1

Since the price (inverse demand) is set at zero, the total surplus available for the consuming business unit is as follows:

$$S_U = \int_0^{D(0,q)} D^{-1}(x,q)dx, \quad x = D(p,q) \tag{8}$$

This expression can be decomposed by the application of integration by parts into the following:

$$\begin{aligned} S_U &= D^{-1}(x,q)\Big|_{D^{-1}(0,q)}^{0} D(p,q)\Big|_0^{D(0,q)} - \int_{D^{-1}(0,q)}^{0} D(p,q)dp \\ &= D^{-1}(0,q)D(0,q) + \int_0^{D^{-1}(0,q)} D(p,q)dp \end{aligned} \tag{9}$$

The firm's maximization problem is as follows : $\underset{q}{Max}\{S_U - C_{IT}\}$

$$\underset{q}{Max}\left\{D^{-1}(0,q)D(0,q) + \int_0^{D^{-1}(0,q)} D(p,q)dp - D(0,q)cq - g(q) - F\right\} \tag{10}$$

By differentiating (10) with respect to quality, the first order condition is generated by applying the product rule and rearranging terms, as follows :

$$D(0,q)\left(D_q^{-1}(0,q) - c\right) + D_q(0,q)\left(D^{-1}(0,q) - cq\right) - g_q(q) + \int_0^{D^{-1}(0,q)} D_q(p,q)dp = 0 \tag{11}$$

Substituting the optimal values for quality q^* from the solution to (11) back into (10) generates the optimal firm value.

$$S_f^{*CC} = D(0,q^{*CC})\left(D^{-1}(0,q^{*CC}) - cq^{*CC}\right) - g(q^{*CC}) + \int_0^{D^{-1}(0,q^{*CC})} D(p,q^{*CC})dp - F \tag{12}$$

Proof of lemma 1

Rearrange the terms in the first order condition (11), solve for $D(0,q)$ which results in the expression

$D(0,q)\big|_{q^{*CC}} = \left(\left(\int_0^{D(0,q)} D_q^{-1}(x,q)dx - cqD_q(0,q) - g_q(q)\right)/c\right)\Bigg|_{q^{*CC}}$ that holds true at the optimal quality and price.

Proof of proposition 2

The price now is nonzero and the total surplus available for the consuming business unit is as follows:

$$S_U = \int_0^{D(p,q)} \left(D^{-1}\left(D(p,q),q\right)\right)dx - \left(D^{-1}\left(D(p,q),q\right)D(p,q)\right) \tag{13}$$

As a profit center with non zero pricing, the IT department profit is expressed as follows:

$$S_{IT} = D(p,q)\left(D^{-1}\left(D(p,q),q\right) - cq\right) - g(q) - F \tag{14}$$

The IT department's maximization problem is as follows : $\underset{p,q}{Max}\{S_{IT}\}$

$$\underset{p,q}{Max}\{D(p,q)(p-cq) - g(q) - F\} \tag{15}$$

By differentiating (15) with respect to quality and then with respect to price, the first order conditions are generated by applying the product rule and rearranging terms, as follows :

$$\begin{bmatrix} D_q(p,q)(p-cq) - D(p,q)c - g_q(q) \\ D_p(p,q)(p-cq) + D(p,q) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \Leftrightarrow \begin{bmatrix} D_q(p,q)/D(p,q) \\ D_p(p,q)/D(p,q) \end{bmatrix}(p-cq) = \begin{bmatrix} \left(g_q(q)/D(p,q)\right) + c \\ -1 \end{bmatrix} \tag{16}$$

The optimal firm values q^{*PC}, p^{*PC} are obtained from the solution to (16). Substituting these values into the firm value which is $S_f = S_U + S_{IT}$ generates the optimal firm value.

$$S_f^{*PC} = \left(\int_0^{D\left(p^{*PC},q^{*PC}\right)} D^{-1}\left(D\left(p^{*PC},q^{*PC}\right),q^{*PC}\right)dx\right) - \left(D\left(p^{*PC},q^{*PC}\right)cq^{*PC} + g(q^{*PC}) + F\right) \tag{17}$$

Proof of lemma 2

Divide the first order condition for $D_q(p,q)$ in (16) by the first order condition for $D_p(p,q)$ and the result is generated. This holds true at the optimal quality and price.

Proof of lemma 3

Subtract the second term in the first order condition (16) from the first term. Solve for $D(p,q)$ which results in the expression $D(p,q)\big|_{p^{*PC},q^{*PC}} = \left(\frac{(p-cq)\left(D_q(p,q) - D_p(p,q)\right) - g_q(q)}{(1+c)}\right)\Bigg|_{p^{*PC},q^{*PC}}$ that holds true at the optimal quality and price.

Proof of proposition 3

Substituting the optimal values for quality q^* from the solution to (11) back into (8) and subtracting the cost of IT provides an alternative expression for cost center firm value.

$$S_f^{*CC} = \left(\int_0^{D\left(0,q^{*CC}\right)} D^{-1}\left(x,q^{*CC}\right)dx \right) - \left(D\left(0,q^{*CC}\right)cq^{*CC} + g(q^{*CC}) + F\right) \tag{18}$$

The difference in firm value is generated as follows :

$$\begin{aligned} S_f^{*PC} - S_f^{*CC} = &\left[\left(\int_0^{D\left(p^{*PC},q^{*PC}\right)} D^{-1}\left(D\left(p^{*PC},q^{*PC}\right),q^{*PC}\right)dx \right) - D\left(p^{*PC},q^{*PC}\right)cq^{*PC} - g(q^{*PC}) - F \right] - \\ &\left[\left(\int_0^{D\left(0,q^{*CC}\right)} D^{-1}\left(x,q^{*CC}\right)dx \right) - D\left(0,q^{*CC}\right)cq^{*CC} - g(q^{*CC}) - F \right] \end{aligned} \tag{19}$$

Multiplying out the expression in (19), setting the difference $\left(S_F^{*PC} - S_F^{*CC}\right)$ to be positive and rearranging terms generates the result.

$$c > \frac{\left(\int_0^{D\left(0,q^{*CC}\right)} D^{-1}\left(x,q^{*CC}\right)dx - \int_0^{D\left(p^{*PC},q^{*PC}\right)} D^{-1}\left(x,q^{*PC}\right)dx \right)}{\left(D\left(0,q^{*CC}\right)q^{*CC} - D\left(p^{*PC},q^{*PC}\right)q^{*PC}\right)} + \left(g(q^{*PC}) - g(q^{*CC})\right) \tag{20}$$

Proof of proposition 4

The difference in consumption of IT services from lemma 1 and lemma is differenced as follows :

$$\begin{aligned} &D(p,q)\Big|_{p^{*PC},q^{*PC}} - D(0,q)\Big|_{q^{*CC}} = \\ &\left(\frac{(p-cq)\left(D_q(p,q) - D_p(p,q)\right) - g_q(q)}{(1+c)} \right)\Bigg|_{p^{*PC},q^{*PC}} - \left(\frac{\left(\int_0^{D(0,q)} D_q^{-1}(x,q)dx - cqD_q(0,q) - g_q(q) \right)}{c} \right)\Bigg|_{q^{*CC}} \end{aligned} \tag{21}$$

Multiplying out the expression in (21), setting the difference $\left(x^{*PC} - x^{*CC}\right)$ to be positive and rearranging terms generates the result.

$$\frac{c}{1+c} > \frac{\left((p-cq)\left(D_q(p,q) - D_p(p,q)\right) - g_q(q)\right)\Big|_{p^{*PC},q^{*PC}}}{\left(\int_0^{D(0,q)} D_q^{-1}(x,q)dx - cqD_q(0,q) - g_q(q) \right)\Bigg|_{q^{*PC}}} \tag{22}$$

Proof of propositions 5

The total surplus available for the consuming business unit is as follows:

$$S_U = \int_0^{(k+\beta q)} \frac{(k+\beta q - x)}{\alpha} dx = (k+\beta q)^2 / 2\alpha \tag{23}$$

The firm’s problem and first order condition is as follows

$$\underset{q}{Max}\left\{\left(\int_{0}^{(k+\beta q)/\alpha}(k+\beta q)dx\right)-xcq-aq^2-F\right\}$$
$$\left(q\beta^2+\beta\left(k-\alpha\left(c+2q\right)\right)-\alpha\left(k+2aq\right)\right)/\alpha=0 \tag{24}$$

The optimal quality to offer is the first order condition:

$$q^{*CC}=\left(k\left(\beta-\alpha\right)-c\alpha\beta\right)/\left(2a\alpha+\beta\left(2\alpha-\beta\right)\right) \tag{25}$$

The base level of quality is modeled to be at $q^{*CC}=0$. Therefore this is a boundary condition. The optimization above can offer a negative (or decrease in quality from the base level) quality value. At the boundary, quality is forced to zero and negative levels are not allowed. Therefore, quality can never be below the base level. Substituting the optimal quality into the firm benefit expression (24), the IT and the functional unit surplus expression (23), the demand function $\left(k-\alpha p+\beta q\right)$ and simplifying, we obtain the required results

$$S_f^{*CC}=\frac{2ak\left(k-2c\alpha\right)+\alpha\left(k-c\beta\right)^2}{2\left(2a\alpha+\beta\left(2\alpha-\beta\right)\right)}-F,\ \ S_U^{*CC}=\frac{\alpha\left(2ak+\beta\left(k-c\beta\right)\right)^2}{2\left(\beta\left(\beta-2\alpha\right)-2a\alpha\right)^2},\ \ x^{*CC}=\frac{\alpha\left(2ak+\beta\left(k-c\beta\right)\right)}{2a\alpha+\beta\left(2\alpha-\beta\right)} \tag{26}$$

<u>Concavity condition</u>: The second derivate of the objective function (24) is given below:

$$\left(\beta\left(\beta-2c\alpha\right)/\alpha\right)-2a \tag{27}$$

concavity requires that the determinant (27) is negative. This in turn requires $a>\beta\left(\beta-2c\alpha\right)/2a$.

<u>Non-negative quality</u>: Setting (25) to be non-negative results in the requirement $c<k\left(2a+\beta\right)/\beta^2$

<u>Non-negative quantity</u>: Setting x^{*CC} in (26) to be non-negative results in the requirement $\beta>c\alpha$, completing the proof.

Proof of proposition 6

The IT department sets optimal price and quality where its profit is given by:

$$S_{IT}=x\left(p-cq\right)-aq^2-F,\ \ x=k-p\alpha+\beta q \tag{28}$$

The IT department's maximization problem and first order conditions are as follows:

$$\underset{p,q}{Max}\left\{\left(k-p\alpha+\beta q\right)\left(p-cq\right)-aq^2-F\right\}$$
$$k+\alpha\left(c-2p+q\right)+q\beta=0 \tag{29}$$
$$p\left(\alpha+\beta\right)-\left(k+c\beta+2q\left(a+\beta\right)\right)=0$$

Solving the first order conditions for optimal price and quality generates the following solution:

$$q^{*PC}=\left(k-c\alpha\right)\left(\beta-\alpha\right)/\left(4a\alpha-\left(\alpha-\beta\right)^2\right) \tag{30}$$

$$p^{*PC}=2a\left(k+c\alpha\right)+\left(\alpha-\beta\right)\left(c\beta-k\right)/\left(4a\alpha-\left(\alpha-\beta\right)^2\right) \tag{31}$$

Substituting (30) and (31) into the expressions for IT surplus and business unit surplus and quantity from the demand function, and simplifying, we obtain the following:

$$S_{IT}^{*PC} = \frac{a\left(k-c\alpha\right)^2}{\left(4a\alpha-\left(\alpha-\beta\right)^2\right)} - F,\ \ S_U^{*PC} = \frac{2a^2\alpha\left(k-c\alpha\right)^2}{\left(4a\alpha-\left(\alpha-\beta\right)^2\right)^2},\ \ x^{*PC} = \frac{2a\alpha\left(k-c\alpha\right)}{\left(4a\alpha-\left(\alpha-\beta\right)^2\right)} \tag{32}$$

The firm benefit is the sum of IT profits and business unit surplus, $S_{IT}^{*} + S_{BU}^{*}$ and is expressed as follows:

$$S_f^{*PC} = a\left(k-c\alpha\right)^2\left(6a\alpha-\left(\alpha-\beta\right)^2\right)/\left(\left(\alpha-\beta\right)^2-4a\alpha\right)^2 \tag{33}$$

<u>Concavity condition</u>: The Hessian matrix of the objective function (28) is given below:

$$\begin{bmatrix} -2\left(a+c\beta\right) & \left(c\alpha+\beta\right) \\ \left(c\alpha+\beta\right) & -2\alpha \end{bmatrix} \tag{34}$$

The determinant is as follows: $4a\alpha-\left(\beta-c\alpha\right)^2$ and concavity requires that the determinant $4a\alpha-\left(\beta-c\alpha\right)^2>0$, since the first principal minor is negative. This in turn requires $a>\left(\beta-c\alpha\right)^2/4a$.

<u>Non-negative quality, quantity and price</u>:. Note that concavity will ensure that the denominator for the expressions for optimal quantity and price is always positive and always negative for optimal quality. Setting (30) to be non-negative results in the requirement $\alpha<\beta/c$ and $\alpha<k/c$ for non-negative quality. This will also ensure positive numerators for optimal quantity and price. Note that this is a sufficient condition for price. A necessary condition for non-negative price is $a>(\beta-\alpha)\left(c\beta-k\right)/2\left(k+c\alpha\right)$ readily obtained by setting (31) to be non-negative.

Proof of proposition 7

The difference in benefit to the firm from IT from a profit center vs. a cost center is:

$$\left(S_f^{*PC}-S_f^{*CC}\right) = \left(\frac{a\left(k-c\alpha\right)^2\left(6a\alpha-\left(\alpha-\beta\right)^2\right)}{\left(\left(\alpha-\beta\right)^2-4a\alpha\right)^2}\right) - \left(\frac{2ak\left(k-2c\alpha\right)+\alpha\left(k-c\beta\right)^2}{2\left(2a\alpha+\beta\left(2\alpha-\beta\right)\right)}\right) \tag{35}$$

Solving for the difference $\left(S_f^{*PC}-S_f^{*CC}\right)>0$ generates two roots:

$$\begin{aligned} &c<\left(Z\pm2\sqrt{2a^3k^2\alpha\left(\left(\alpha-\beta\right)^2-4a\alpha\right)^2\left(2a\alpha+\beta\left(2\alpha-\beta\right)\right)}\right)/X \\ &Z\equiv k(-8a^3\alpha^2+4a^2\alpha^2(3\alpha-4\beta)-2a\alpha(\alpha-4\beta)(\alpha-\beta)^2-(\alpha-\beta)^4\beta) \\ &X\equiv(24a^3\alpha^3-2a\alpha(2\alpha-5\beta)(\alpha-\beta)^2\beta-(\alpha-\beta)^4\beta^2-4a^2\alpha^2(\alpha^2-8\alpha\beta+8\beta^2)) \end{aligned} \tag{36}$$

This condition can be readily checked by adding a non-negative quantity M to the right hand side of (36) into the optimal quality for the profit center which is expressed as:

$$\left((\alpha-\beta)(k-\alpha\left(M+\frac{Z\pm 2\sqrt{2a^3k^2\alpha\left((\alpha-\beta)^2-4a\alpha\right)^2\left(2a\alpha+\beta\left(2\alpha-\beta\right)\right)}}{X}\right)\right)\right)/\left((\alpha-\beta)^2-4a\alpha\right) \tag{37}$$

For an interior solution, note that the denominator of (37) is required to be positive from proposition 6. Therefore, the numerator needs to be positive for a positive interior quality solution. Solving the numerator of (37) for M results in the following:

$$M=\left(k\left((\alpha-\beta)^2-4a\alpha\right)^2\left(2a\alpha+(\alpha-\beta)\beta\right)\mp 2\sqrt{2}\alpha\sqrt{a^3k^2\alpha(-4a\alpha+(\alpha-\beta)^2)^2(2a\alpha+(2\alpha-\beta)\beta)}\right)/\left(\alpha X\right) \tag{38}$$

First, note that the first term in (38) which is $k\left((\alpha-\beta)^2-4a\alpha\right)^2\left(2a\alpha+(\alpha-\beta)\beta\right)$ is always positive from the concavity requirements from propositions 5 and 6. Second, note that the signs are reversed on the square root term. If the negative root form (36) was the threshold the result would be $M>\left(\begin{matrix}k\left((\alpha-\beta)^2-4a\alpha\right)^2\left(2a\alpha+(\alpha-\beta)\beta\right)+\\ 2\sqrt{2}\alpha\sqrt{a^3k^2\alpha(-4a\alpha+(\alpha-\beta)^2)^2(2a\alpha+(2\alpha-\beta)\beta)}\end{matrix}\right)/\left(\alpha X\right)$. The right hand side is positive when X is positive and sufficiently small values of M will not be viable, which is a contradiction. On the other hand, if X is negative, negative values of M are viable and this is again a contradiction. Therefore, the first root is the only feasible root in the interior.

Proof of proposition 8

The difference in optimal quality for the two governance structures is expressed as follows:

$$\left(q^{*PC}-q^{*CC}\right)=\left(\frac{(k-c\alpha)(\beta-\alpha)}{4a\alpha-(\alpha-\beta)^2}-\frac{k(\beta-\alpha)-c\alpha\beta}{2a\alpha+\beta(2\alpha-\beta)}\right) \tag{39}$$

Solving (39) for the intercept we obtain the result, $k>\frac{c\alpha\left(2a\left(\beta+\alpha\right)-\beta\left(\beta-\alpha\right)\right)}{\left(2a-\alpha\right)\left(\beta-\alpha\right)}$. Further solving for a positive intercept generates the requirement that $\alpha>\beta\left(\beta-2a\right)/\left(2a+\beta\right)$ and a positive threshold for α further requires that $a<\beta/2$. This completes the proof.

Proof of proposition 9

The difference in optimal quantity of IT services consumed for the two governance structures is expressed as follows:

$$\left(x^{*CC}-x^{*PC}\right)=\left(\frac{k\alpha\left(2a+c\beta\right)}{2a\alpha+\beta\left(2c\alpha-\beta\right)}-\frac{2a\alpha\left(k-c\alpha\right)}{4a\alpha-\left(\alpha-\beta\right)^2}\right) \tag{40}$$

Solving (40) for the fixed cost of quality parameter a, we obtain the following two solutions:

$$a < \left(\begin{array}{l} c\alpha\beta(3\beta - 2\alpha) - k\alpha(2\beta - \alpha) \pm \\ \sqrt{\alpha\left(k^2\alpha^3 + 2k\alpha\beta^2(c\alpha - 2k) + 4\beta^3(k - c\alpha)(k + c\alpha) + c\beta^4(5c\alpha - 4k)\right)} \end{array} \right) / 4\alpha(k + c\alpha) = A \qquad (41)$$

To test the negative root, let M be a positive real number and set the value of the fixed cost of quality parameter as $a = A - M$. Solving this expression for M we obtain:

$$M = \frac{\left(\begin{array}{l} k^2\alpha^2 + ck\alpha\beta^2 - 2c^2\alpha^2\beta^2 - \\ \sqrt{k^4\alpha^4 - 4k^4\alpha^2\beta^2 + 2ck^3\alpha^3\beta^2 + 4k^4\alpha\beta^3 - 4c^2k^2\alpha^3\beta^3 - 4ck^3\alpha\beta^4 + 5c^2k^2\alpha^2\beta^4} \end{array} \right)}{4k\alpha(k + c\alpha)} \qquad (42)$$

Compare the positive terms $k^2\alpha^2 + ck\alpha\beta^2$ outside the square root in (42) with terms inside the root sign. The terms inside the root sign $k^4\alpha^4 + 5c^2k^2\alpha^2\beta^4$ dominate the terms outside resulting in a negative value for M which is a contradiction. Therefore the positive root is the valid solution and we have

$$a < \frac{\left(\begin{array}{l} c\alpha\beta(3\beta - 2\alpha) - k\alpha(2\beta - \alpha) + \\ \sqrt{\alpha\left(k^2\alpha^3 + 2k\alpha\beta^2(c\alpha - 2k) + 4\beta^3(k - c\alpha)(k + c\alpha) + c\beta^4(5c\alpha - 4k)\right)} \end{array} \right)}{4\alpha(k + c\alpha)} = A,$$ completing the proof.

Proof of proposition 10

The difference in function unit surplus from the two governance models is expressed as follows:

$$\left(S_U^{*CC} - S_U^{*PC}\right) = \left(\frac{(k + q^{*CC}\beta)^2}{2\alpha} - \frac{2a^2\alpha(k - c\alpha)^2}{\left(4a\alpha - (\alpha - \beta)^2\right)^2} \right) \qquad (43)$$

Solving (43) for q^{*CC} generates the following tow solutions:

$$q^{CC} > \frac{k(\alpha - \beta)^2 - 2a\alpha(k + c\alpha)}{(4a\alpha - (\alpha - \beta)^2)\beta}, \qquad q^{CC} > \frac{k(\alpha - \beta)^2 + 2a\alpha(c\alpha - 3k)}{(4a\alpha - (\alpha - \beta)^2)\beta} \qquad (44)$$

The quantity of IT services consumed may be computed for each solution under the cost center structure and we generate the following consumption quantity: $x = \frac{\pm 2a\alpha(k - c\alpha)}{4a\alpha - (\alpha - \beta)^2}$. The quantity consumed is required to be positive. From proposition 6, the profit center concavity requirements require that the denominator $4a\alpha - (\alpha - \beta)^2$ is positive and that $k > c\alpha$. Therefore, only the first solution is viable and we have $q^{CC} > \frac{k(\alpha - \beta)^2 - 2a\alpha(k + c\alpha)}{(4a\alpha - (\alpha - \beta)^2)\beta}$, completing the proof.

Proof of proposition 11

Earlier, proposition 7 provides the first crossover point which is for the optimal governance structure. We need to generate the crossover point between the firm benefit under a cost center and the IT profit under the profit center. This difference is as follows:

$$\left(S_f^{*CC}-S_{IT}^{*PC}\right)=\left(\frac{k^2\left(2a+c^2\alpha\right)}{2\left(2a\alpha+\beta\left(2c\alpha-\beta\right)\right)}-\frac{a\left(k-c\alpha\right)^2}{4a\alpha-\left(\alpha-\beta\right)^2}\right) \tag{45}$$

Solving (45) for the marginal cost we obtain the following two solutions for the cost center firm benefit to be greater than IT profit:

$$c<\left(\frac{k\beta\left(\alpha-\beta\right)^2-2ak\alpha\left(2\left(a+\beta\right)-\alpha\right)\pm}{2\sqrt{a^2k^2\left(4a\alpha-\left(\alpha-\beta\right)^2\right)\left(2a\alpha+\beta\left(2\alpha-\beta\right)\right)}}\right)/\,2a\alpha\left(2\alpha\left(a+1\right)-3\beta\right)+\left(\beta\left(\alpha-\beta\right)\right)^2 \tag{46}$$

To test the negative root, as before, let M be a positive real number and set the marginal cost to be lower than this threshold by the quantity M. Solving the resulting expression for M we obtain:

$$M=-\frac{4\sqrt{a^2k^2(4a\alpha-(\alpha-\beta)^2)(2a\alpha+(2\alpha-\beta)\beta)}}{2a\alpha\left(2a\alpha+(2\alpha-3\beta)\beta\right)+\left(\alpha-\beta\right)^2\beta^2} \tag{47}$$

A positive denominator for (47) requires that $\alpha>3\beta^2/2(a+\beta)$, which imposes a more restrictive constrain than the const center concavity requirement from (27) which is $\alpha>\beta^2/2(a+\beta)$. With this constraint, (47) requires that M is negative, which is a contradiction. Therefore, the negative root is eliminated and $c<\left(\frac{k\beta\left(\alpha-\beta\right)^2-2ak\alpha\left(2\left(a+\beta\right)-\alpha\right)+}{2\sqrt{a^2k^2\left(4a\alpha-\left(\alpha-\beta\right)^2\right)\left(2a\alpha+\beta\left(2\alpha-\beta\right)\right)}}\right)/\,2a\alpha\left(2\alpha\left(a+1\right)-3\beta\right)+\left(\beta\left(\alpha-\beta\right)\right)^2$

completing the proof.

Proof of proposition 12

The cloud vendor's price and quality is expressed as follows:

$$q_C,\quad \left(c+\theta\cdot q_C\right) \tag{48}$$

The new marginal cost to the firm is now given by $\left(c+\theta\cdot q_C\right)$ and the fixed cost of quality for the IT department is the incremental fixed cost to improve the quality and is given by $a\cdot\left(q^2-q_C^2\right)$ where q

<u>Cost center:</u> From proposition 5, the functional unit surplus is given by (23) as $(k+q\beta)^2/2\alpha$. The cost of IT services is $\left(x\cdot\left(c+\theta\cdot q_C\right)+a\cdot\left(q^2-q_C^2\right)\right)$. The internal demand under the cost center is $x=\left(k+q\beta\right)$ and the firm’s maximization problem and first order condition is as follows

$$\begin{gathered}\underset{q}{Max}\left\{\left(\int_0^{(k+\beta q)}\frac{\left(k-x+\beta q\right)}{\alpha}dx\right)-\left(x\cdot\left(c+\theta\cdot q_C\right)+a\cdot\left(q^2-q_C^2\right)\right)\right\}\\ k+2aq+q\beta-\frac{\beta\left(k+q\beta\right)}{\alpha}+\beta\left(c+q+q_C\left(\theta-1\right)\right)=0\end{gathered} \tag{49}$$

The optimal quality to offer is obtained from the first order condition:

$$q_C^{*CC} = \frac{k(\beta-\alpha)-\alpha\beta\left(c+q_C(\theta-1)\right)}{2a\alpha+\beta(2\alpha-\beta)} \tag{50}$$

The quantity of IT services consumed is generated from the demand function $x_C^{*CC} = k + \beta q_C^{*CC}$. The cost of IT services under cloud computing is $\left(x_C^{*CC}\cdot(c+\theta\cdot q_C)+a\cdot\left(\left(q_C^{*CC}\right)^2-q_C^2\right)\right)$. The net benefit to the firm is $S_{fC}^{*CC} = S_{UC}^{*CC} - \left(x_C^{*CC}\cdot(c+\theta\cdot q_C)+a\cdot\left(\left(q_C^{*CC}\right)^2-q_C^2\right)\right)$, which generates the following:

$$S_{fC}^{*CC} = \begin{pmatrix} 2a\cdot\begin{pmatrix} 2a\cdot\alpha\cdot q_C^2+k^2+q_C^2\cdot\beta\cdot(2\alpha-\beta)- \\ 2k\cdot\alpha\cdot\left(c+q_C\cdot(\theta-1)\right) \end{pmatrix} \\ +\alpha\cdot\left(k-\beta\cdot\left(c+q_C\cdot(\theta-1)\right)\right)^2 \end{pmatrix} / \, 2a\cdot\alpha+\beta\cdot(2\alpha-\beta) \tag{51}$$

<u>Profit center:</u> The IT department profit is given as $x\cdot\left(p-(c+\theta\cdot q_C)\right)-a\cdot\left(q^2-q_C^2\right)$. The IT department's maximization problem and first order conditions lead to the following:

$$\underset{p,q}{Max}\left\{x\cdot\left(p-(c+\theta\cdot q_C)\right)-a\cdot\left(q^2-q_C^2\right)\right\} \tag{52}$$

$$\begin{aligned} p_C^{*PC} &= \frac{2a\left(k+\alpha\left(c+q_C(\theta-1)\right)\right)}{4a\alpha-(\alpha-\beta)^2}+q_C^{*PC} \\ q_C^{*PC} &= \frac{(\beta-\alpha)\left(k-\beta\left(c+q_C(\theta-1)\right)\right)}{4a\alpha-(\alpha-\beta)^2} \end{aligned} \tag{53}$$

The optimal quantity of IT services consumed is $x_C^{*PC} = k-\alpha p_C^{*PC}+\beta q^{*PC}$ and the benefit to the firm is given by the following:

$$\int_0^{x_C^{*PC}}\left(\frac{k-y+(\beta\cdot q_C^{*PC})}{\alpha}\right)dy-\left(x_C^{*PC}\cdot(c+\theta\cdot q_C)+a\cdot\left(\left(q_C^{*PC}\right)^2-q_C^2\right)\right) \tag{54}$$

Evaluating and simplifying (54) generates the following result for the benefit to the firm:

$$S_{fC}^{*PC} = a\begin{pmatrix} (k-c\cdot\alpha)^2\left(6a\cdot\alpha-(\alpha-\beta)^2\right)+2q_C\cdot\alpha(k-c\alpha)\left((\alpha-\beta)^2-6a\cdot\alpha\right)(\theta-1) \\ +q_C^2\begin{pmatrix} 16a^2\alpha^2-(\alpha-\beta)^2\left(\beta+\alpha(\theta-2)\right)(\alpha\cdot\theta-\beta)+ \\ 2a\cdot\alpha\left(8\alpha\cdot\beta-4\beta^2+\alpha^2\left(3\theta(\theta-2)-1\right)\right) \end{pmatrix} \end{pmatrix} / \left((\alpha-\beta)^2-4a\cdot\alpha\right)^2 \tag{55}$$

This completes the proof.

Proof of proposition 13

Under cloud computing, the difference in firm benefit from the two governance structures is expressed as follows:

$$S_{fC}^{*PC} - S_{fC}^{*CC} = \frac{a\begin{pmatrix}(k-c\cdot\alpha)^2\left(6a\cdot\alpha-(\alpha-\beta)^2\right)+2q_C\cdot\alpha(k-c\alpha)\left((\alpha-\beta)^2-6a\cdot\alpha\right)(\theta-1)\\ +q_C^2\begin{pmatrix}16a^2\alpha^2-(\alpha-\beta)^2\left(\beta+\alpha(\theta-2)\right)(\alpha\cdot\theta-\beta)+\\ 2a\cdot\alpha\left(8\alpha\cdot\beta-4\beta^2+\alpha^2\left(3\theta(\theta-2)-1\right)\right)\end{pmatrix}\end{pmatrix}}{\left((\alpha-\beta)^2-4a\cdot\alpha\right)^2} - \begin{pmatrix}2a\cdot\begin{pmatrix}2a\cdot\alpha\cdot q_C^2+k^2+q_C^2\cdot\beta\cdot(2\alpha-\beta)-\\ 2k\cdot\alpha\cdot\left(c+q_C\cdot(\theta-1)\right)\end{pmatrix}\\ +\alpha\cdot\left(k-\beta\cdot\left(c+q_C\cdot(\theta-1)\right)\right)^2\end{pmatrix} / 2a\cdot\alpha+\beta\cdot(2\alpha-\beta) \tag{56}$$

Solving (56) for the parameter θ or q_C generates the two crossover points:

$$q_C > \frac{\begin{pmatrix}\begin{pmatrix}8a^3\alpha^2(k+3c\alpha)+(\alpha-\beta)^4\beta(k-c\beta)-2a\alpha(\alpha-\beta)^2\\ \left(k(4\beta-\alpha)+c\beta(2\alpha-5\beta)\right)\\ -4a^2\alpha^2\left(\alpha(3k+c\alpha)-4\beta(k+2c\alpha)+8c\beta^2\right)\end{pmatrix}(1-\theta)+\\ 2\sqrt{2}\sqrt{a^3k^2\alpha\left((\alpha-\beta)^2-4a\alpha\right)^2\left(2a\alpha+(2\alpha-\beta)\beta\right)(\theta-1)^2}\end{pmatrix}}{\begin{pmatrix}24a^3\alpha^3-2a\alpha(2\alpha-5\beta)(\alpha-\beta)^2\beta\\ -(\alpha-\beta)^4\beta^2-4a^2\alpha^2\left(\alpha^2-8\alpha\beta+8\beta^2\right)\end{pmatrix}(\theta-1)^2} \tag{57}$$

$$\theta > \frac{\begin{pmatrix}2\sqrt{2}\sqrt{a^3k^2q_C^2\alpha\left((\alpha-\beta)^2-4a\alpha\right)^2\left(2a\alpha+(2\alpha-\beta)\beta\right)}\\ +q_C\cdot\begin{pmatrix}8a^3\alpha^2(k+3c\alpha)+(\alpha-\beta)^4\beta(k-c\beta)-2a\alpha(\alpha-\beta)^2\\ \left(k(4\beta-\alpha)+c\beta(2\alpha-5\beta)\right)\\ -4a^2\alpha^2\left(\alpha(3k+c\alpha)-4\beta(k+2c\alpha)+8c\beta^2\right)\end{pmatrix}\end{pmatrix}}{q_C^2\cdot\begin{pmatrix}24a^3\alpha^3-2a\alpha(2\alpha-5\beta)(\alpha-\beta)^2\beta\\ -(\alpha-\beta)^4\beta^2-4a^2\alpha^2\left(\alpha^2-8\alpha\beta+8\beta^2\right)\end{pmatrix}} \tag{58}$$

This completes the proof.

Boundary condition results

The boundary condition results can be readily generated by setting the quality level $q=0$ for the computations under the two governance structures.