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# OPTIMAL VALUATION AND TIMING OF PRICE BENCHMARKS FOR IT SERVICES CONTRACTS

*Valorisation et timing optimaux des benchmarks de prix pour les contrats de service informatique*

*Completed Research Paper*

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## **Abstract**

*Information technology (IT) services contracts often contain provisions for benchmarking fixed prices to current market prices. Prices of IT services tend to be opaque, but can be revealed through third-party benchmarks. Little research has been conducted on the value and timing of such benchmarks. We draw upon the theory of mortgage refinance and value-at-risk analysis from financial economics, and the IT investment under uncertainty literature to create a model of the benchmarking decision for IT services contracts. Our model permits the determination of the value and optimal timing of the benchmark. We provide conditions under which a client firm should consider one or multiple benchmark provisions. Our solution is robust to uncertainty surrounding benchmark forecasts. Firms can leverage market price uncertainties and exercise benchmarks even when the potential rate of declining IT prices does not reach a minimum threshold to benchmark.*

**Keywords:** Benchmarking, Contracts, Financial Economics, Investment under Uncertainty, IT Services, Risk Management, Service-Level Agreements, Service Science, Value-at-Risk.

## Résumé

Les contrats de service informatiques comportent souvent des clauses de benchmark des prix fixés sur les prix courants de marchés. La recherche a peu traité la question de la valeur et du timing de ces benchmarks. Nous nous appuyons sur la littérature en économie financière et sur les investissements en TI en contexte d'incertitude, afin de valoriser les stratégies de benchmark dans les contrats de services informatiques. Notre modèle informe à la fois les clients et les fournisseurs lors de la négociation et de la réalisation des clauses de benchmark.

## Introduction

Contracting for information technology (IT) outsourcing services involves the transfer of risk among parties. In fact, the uncertainties associated with the management, delivery and cost of IT solutions often serve as drivers for a firm to outsource. Clients expect to benefit from a provider's unique expertise and efficiencies in delivering services, albeit at a competitive price. As technology costs fall, and competition increases, *service-level agreement* (SLA) prices that a provider and a client agreed upon at the outset of the contract may not be competitive as time passes. As a result, many clients insist on a provision in their IT services contracts for benchmarking. *Benchmarking* is the process of seeking a third-party estimate of the current market price for the IT solution, as a means to gauge how close the price of the contracted services are to prevailing external prices.

Benchmarking provisions are the result of information asymmetries between clients and providers of IT services. Clients cannot generally track the prevailing market price for IT services. Provider firms, due to their frequent client interaction and negotiation have more accurate market price information than do client or third-party benchmarkers. As a senior executive of EDS stated: "The reality is I have much better information than the benchmarkers do ... we participated in over 9,000 deals last year" Overby (2007a). Though it is believed that benchmark provisions benefit clients more than providers, there has been little analytic or empirical research to determine how much clients benefit from benchmarking and under what circumstances they should negotiate for, and ultimately exercise benchmark provisions. Benchmark data are notoriously hard to come by (Harris 2007), and there is often little incentive for either client or provider firms to share the intricacies of their IT services contracts. In this paper, we seek to build analytic model to extend existing theory in financial economics to provide managerial guidance on the valuation and timing of benchmarks for IT services that will aid in SLA contract design and contract negotiation. Specifically, we ask: what is the value of including a benchmark provision to a client? What is the optimal time and frequency of exercising benchmark provisions in an IT services contract? How will uncertainty about the variety of IT service contract cost drivers affect these decisions?

### *Characteristics of Price Benchmarks for IT Services*

The key uncertainty driving the need for benchmarking emanates from the changing future market prices for various inputs that constitute the cost drivers of SLAs. In long-term outsourcing arrangements, *ex ante* price adjustment schedules are often included to account for changes in service scope, inflation or process improvements. Benchmarking works as a means to address the drift of relevant market prices away from the original IT services contract price. This drift often is the result of innovations in service delivery, declining technology costs, and increased competition (Harris 2007). Viewed this way, long-term contracts provide stability benefits for both parties. They also may limit the ability of the client firm to access the most competitive market rates for services though.

Methodology-wise, the process of benchmarking can hardly be considered an exact science in current industry practice. Third-party benchmark firms (which we will refer to as *benchmarkers*) access pricing data on the cost-drivers from various kinds of IT services outsourcing arrangements. One of the market leaders in third-party benchmark firms is TPI ([www.tpi.net](http://www.tpi.net)) that specializes in outsourcing advisory services (Harris 2007). Analyst firms such as Gartner and IDC also provide benchmarking services. In addition, many consulting firms offer benchmark services. Data are collected through surveys of existing IT services clients in the marketplace to get a sample of IT service delivery terms and pricing. Since IT services engagements generally vary in content across client engagements, benchmarking firm must adjust for these differences. This process is called *normalization*, and it involves adjusting prices for differences in services such as scale, scope or delivery location (Overby 2007a). The normalized data are then compared to the original prices that are stipulated in the SLA agreement. Since the market for IT services is relatively opaque,

benchmarkers often struggle to achieve access to the relevant data. SLA contracts also often include predetermined thresholds as a basis for determining whether a price adjustment can take place – either reducing or increasing the price for IT services rendered. Harris (2007) reports that some benchmark provisions hold the provider responsible to be no greater in price than the prices associated with the upper quartile or upper decile of all prices observed in the marketplace, while other contracts may utilize a confidence level around the sample mean. Beyond the fact that IT outsourcing contracts are heterogeneous, the author also mentions that benchmarks are usually conducted with a small sample size, about eight to ten contracts. This is a cause for concern relative to the overall accuracy. Client firms may benefit through inter-organizational sharing of outsourcing contract data. If the current price does not meet a *designated benchmark threshold*, enforcement mechanisms included in the contract may provide a legal basis for automatically adjusting prices, or allowing the client or the vendor to abandon the IT services arrangement.

### ***Benchmarking Strategies and Their Countervailing Benefits to Providers and Clients***

It may not be surprising that benchmarking provisions are popular among IT services clients, but they tend to be much less popular among IT services providers. Benchmarks cut into a provider firm's profit when the underlying cost drivers for IT services can be controlled or are headed in the "right" direction (as with a decline in the price of software labor, for a given kind of software development). Also, like warranties on consumer electronics, providers' pricing schemes create profits at the back-end of SLA contracts (Overby 2007a). Seeking to shift the balance of power in IT service relationships away from the provider's side, many client firms have adopted a strategy of employing benchmarking provisions, resulting in micro-price adjustments with frequent invocations of the benchmarks (Harris 2007). Practitioners differ in the advice they give clients regarding benchmark frequency though. Some suggest consistent yearly intervals (Overby 2007b). Others promote the use of infrequent benchmarks after at least eighteen months in contracts with durations of longer than three years (Harris 2007). The latter approach seeks to use the benchmark as a risk mitigation tool, while the former views the benchmark as more of a micro-pricing tool.

Providers have turned to several strategies to mitigate the effects of client-mandated benchmark clauses on their profits. One approach they employ now is to request a cap on the post-benchmark price adjustment. Providers can also seek to limit the timing or frequency of the benchmark decision (Overby 2007b). An emerging trend among providers is to limit the use and reuse of client data for benchmarks (Overby 2007a). By stifling access to data, providers can limit the ability of a benchmark to be carried out, per the terms of the contract. In addition, there is added uncertainty as to whether the benchmark will accurately reflect market prices. Such uncertainty has the potential to affect either party adversely.

The present research is motivated by these considerations. We will model the value of contract price information in the context of IT services benchmarks, and answer a number of questions. How much should clients be willing to pay for embedded options for benchmarking in their IT services contracts? How can we characterize how optimal timing choices for benchmarking should be established? Will IT service providers be worse off if their prices for benchmarking services were transparent? What other managerially-relevant findings can be extracted from simple models of benchmarking? We will explore different conditions for expected rates of the declining market prices and the related uncertainties, which result in firm preferences for early, frequent benchmarks are preferred to later, more infrequent benchmarks.

### ***Existing Theory and a New Approach***

Two streams of literature to support development of a model of optimal benchmark timing. The first includes Dunn and Spatt (2005), and Argarwal et al. (2007), which describe the methods developed to support consumer refinancing decisions, and lender pricing strategies for home mortgages. They model the optimal timing of refinancing decisions. The basic tenet of the theory is that consumers should be indifferent for refinancing when the net present value (NPV) of the benefits of refinancing is equal to the refinancing costs, plus the difference in value between the option to refinance which one gives up, and the option to refinance which one gains over the remaining life of the contract (Agarwal et al. 2007).

In the case of IT services contracts, we note two important modeling differences. First, with IT services benchmarking, the markets in which relevant SLA contract prices are established are quite opaque. The market prices for IT services contracts generally cannot be observed in the market without costly effort. This lack of market transparency is the *raison d'être* for benchmarking services; the market's willingness-to-pay third-party benchmarkers for their services suggests that there is more than just nominal value asso-

ciated with their intermediation. As a result, when we model optimal benchmarking for IT services, we must consider the optimal timing, given expectations about the uncertainty about the price trajectories of various aspects of IT services. In contrast, mortgage refinancing strategy is often framed in terms of an *interest rate boundary*, a single key parameter with important value referents, across which it is optimal to refinance. For mortgages, it is unnecessary to specify any limits on the amount of time that must pass before a consumer is able to refinance. This is not possible in the IT services contracting though. For IT services contracts with embedded benchmarking options, it typically will be necessary to make an *ex ante* decision with incomplete information about the optimal time during the lifetime of the SLA contract when it is possible for either or both parties to exercise the option to invoke the benchmark. The incomplete information aspect of this decision-making setting arises based on transparency for the given IT services being analyzed (e.g., software, web hosting, data center operation, and so on).

A second key difference between the mortgage refinance decision and the IT services benchmarking decision comes with whether the embedded option can be exercised once only or more than one time. The mortgage example is obvious: refinancing a mortgage means that the original contract is extinguished, and a new one replaces it. But a borrower always holds the option to refinance the new loan. This is not quite the same for IT services benchmarking though; it is still possible to benchmark an SLA contract more than once, only these will occur at different points in time. For simplicity in the development of our managerial analysis and contract design policy strategies, we will consider one benchmark per contract in our base model, and then extend the model to two benchmarks over a given contract time horizon.

We also consider risk management models that evaluate optimal time to *mark-to-market* (MTM), as discussed by Liao and Theodosopoulos (2005). The authors considered the changes in market values of over-the-counter stock derivative positions with respect to collateral posted at the initiation of the derivative contract. We draw an analogy between marking-to-market financial instruments with the benchmarking of IT services contracts. *Mark-to-market* is the periodic valuation of assets held. TPI (2008) refers to its benchmarking approach as an *IT mark-to-market method*. In their model, the stock prices are not observed until the mark-to-market takes place, and substantial expenses for this financial intermediation service are associated with the mark-to-market process. IT services benchmarks share these characteristics. The authors also extend the previous mark-to-market literature by considering the potential of using quantile-based analysis to calibrate different risk exposure levels. In the case of benchmarking, we are evaluating the cumulative price paid throughout the contract life and minimizing this in the objective function of our optimization function. On the other hand, the authors also consider the maximum risk exposure over the life of the stock derivative contract and the probability of default on any given day as their key parameters.

We combine elements of refinancing and risk management theory, as well as draw on literature regarding IT investment under uncertainty to build a unique model which values benchmark decisions in opaque markets. To our knowledge, few researchers have considered optimal timing in opaque markets and the value of flexibility under price uncertainty, so we believe this to be a broad contribution to the stream of literature around investment in uncertainty. The next section sets up the modeling concepts. We first consider the results of the model with a known, constant price decline in order to establish a baseline case with which to compare results under uncertainty. We then incorporate the effects of uncertainty. Our modeling results are robust in the face of volatility. We show that firms can leverage uncertainty by exercising benchmarks even when the expected price decreases are modest. We find that increases in the dollar value of the benchmark threshold will tend to reduce the time to exercise and the value of the benchmark option. These findings may be counter-intuitive given the dynamics of conventional options models where the increase in the length of time to expiration increases the value of the option.

## Model

### *IT Services Contracts and Benchmarking for Price*

Imagine that a provider of IT outsourcing services negotiates a fixed-price, fixed-length contract with a client. Service-level agreements regarding quality and time of service are defined in the contract. The SLA prices are assumed to be index-adjusted for inflation. The provider minimizes the cost of providing the service in order to maximize profits under the fixed-price contract.

We consider the case with declining costs of IT and increasing competition in the IT services industries,

and the market prices of the outsourced service are expected to decline as time goes on. Demirhan et al. (2006) provide a formal model of declining technology costs and the impact on IT investments. The client requests a benchmark provision in the contract. The benchmark provision can cover multiple distinct services, for example, desktop support or network management. Under the benchmark provision, a third-party consultant, agreed to *ex ante* by both the client and the provider, will examine the market prices for IT services and provide a benchmark. According to the terms of the contract, price adjustments for the SLA will be made based upon the benchmark results, but will only result in decreases in price to the clients. We consider first the case of a single benchmark allowed during the contract life cycle. We later extend the model to cover multiple periods.

### Model Specification

The client and provider agree to a contract with a fixed price at the start of the contract,  $P$ , for a contract lifetime of  $T$ . The price  $P$  is paid in continuous time over an interval of  $dt$ . *Continuous time analysis* allows us to obtain more general results and is often more tractable in terms of achieving closed form solutions. We expect the model to be implemented over a discrete schedule of payment intervals (e.g., monthly, or quarterly). Our modeling results hold under discrete time analysis too.

The modeling notation is giving in Table 1.

Table 1. Modeling Notation	
Variable	Description
$C$	Total contract costs
$T$	Total length of contract
$P$	Price paid in services contract
$t$	Time at which benchmark is estimated
$\mu$	Expected drift rate of market prices
$\sigma$	Standard deviation of annual price drift rate
$X$	Transaction costs as costs of benchmarking services

The *price-at-benchmark*,  $P_t$ , is the price observed by the third-party consultant by calling a benchmark at time  $t$ . At  $t = 0$ , the client and provider have negotiated the price according to the available benchmarking data to arrive at  $P_0$ <sup>1</sup>. As time progresses, the price-at-benchmark is unobserved, and is assumed to evolve via geometric Brownian motion with a *drift rate*  $\mu$  and a *diffusion parameter*  $\sigma$ . The drift rate,  $\mu$ , represents the rate of change of market prices of IT services over time.<sup>2</sup> We assume a drift rate of  $\mu < 0$ , so prices for the IT services are expected to decline over time in the presence of market competition and technological advances. The *standard deviation of the benchmark price drift* ( $\sigma$ ) represents the diffusion or variation associated with the price-at-benchmark:

$$dP = \mu P dt + \sigma P dz \quad (1)$$

The use of geometric Brownian motion with drift has precedent in modeling *IT investments under uncertainty* (Schwartz and Zozaya-Gorostiza 2004), as well as *general investments under uncertainty models* (Dixit and Pindyck 1994).<sup>3</sup>

## Optimal Timing of Benchmark: The Baseline Case

<sup>1</sup> We do not consider a *discount rate*. Our analysis of IT services contract costs is independent of the discount rate. Discounts apply uniformly to contract cost, whether the service is priced at the original rate or at the benchmark rate.

<sup>2</sup> In traditional models of financial economics, the term *growth rate* is used for the drift term  $\mu$  that use here. Since our model is restricted to *price declines* ( $\mu < 0$ ), we avoid the term *growth rate* and instead use the more neutral term *drift rate*. We also use the phrase *rate of price decline* when discussing the case of negative drift of the market price of IT services.

<sup>3</sup> Our results are limited to the pricing dynamics specified, and imply a concave decreasing price function. If future empirical work we will extend the model to address functional forms which may provide concave up decreasing prices, or even an S-curve, such as the Bass (1969) diffusion-based model.

In our first analysis, we will establish the optimal timing of the IT services benchmark assuming there is no volatility in the drift of the market prices of IT services, so  $\sigma = 0$ . We expect that any forecast of price declines would be affected by uncertainty, so this initial model is a baseline case with which to compare later results. We assume the benchmark triggers a price adjustment regardless of the value of  $P_t$  relative to  $P_0$ . Given a drift rate of  $\mu$ , the price at benchmark is  $P_t = P_0 e^{\mu t}$  where we assume  $\mu < 0$ . The objective is:

$$\text{Min } C = P_t t + P_t e^{\mu(T-t)} \quad (2)$$

This permits us to state our first proposition:

- **Proposition 1 (The Optimal Benchmark Timing Proposition).** *Under conditions of a constant, negative exponential decline in prices, the optimal time to exercise a benchmark occurs at:*

$$t^* = \frac{\mu T + W(e^{1-\mu T}) - 1}{\mu}$$

**Sketch of Proof.** The first-order conditions are given by:

$$\frac{dC}{dt} = 1 - e^{\mu t} - e^{\mu t} \mu t + e^{\mu t} \mu T = 0 \quad (3)$$

Therefore,  $t^* = \frac{\mu T + W(e^{1-\mu T}) - 1}{\mu}$ . In this expression,  $W$  is the Lambert  $W$  function,  $\mu \neq 0$ , and  $t^*$  is a local minimum over the interval where  $t = [0, 1]$ .<sup>4</sup> In addition, the second-order conditions are also satisfied:

$$\frac{d^2C}{dt^2} = -2e^{\mu t} + e^{\mu t} \mu^2 - e^{\mu t} \mu^2 T < 0 \quad \text{over the interval where } \mu, t \in [0, 1] \quad (4)$$

- **Proposition 2 (The Optimal Benchmark in the First Half of the Contract Proposition).** *With a negative drift rate of prices ( $\mu < 0$ ), the optimal benchmark period will always occur in the first half of the contract.*

**Sketch of Proof:** From the Optimal Benchmark Timing Proposition (P1),  $\mu \rightarrow 0$ , the term  $W(e^{1-\mu T}) \rightarrow 1 - .5(\mu T)$ . P1 then reduces to:  $\frac{\mu T - \frac{1}{2}\mu T}{\mu}$ , which implies that as  $\mu \rightarrow 0$ ,  $t^* \rightarrow T/2$ , where  $t^*$  is the optimal time to benchmark the contract and  $T$  is the total length of the contract.

The Optimal Benchmark Timing Proposition (P1) and the related Optimal Benchmark in First Half of the Contract Proposition (P2), along with the assumption that benchmarks do not trigger price increases, implies that the  $t = T/2$  is an upper bound to the benchmark decision. Apparently, it will never be optimal to benchmark in the second half of the contract.

### Value of the IT Services Contract Benchmark Provision

One of the motivating factors in this work is to understand the value of implementing an IT services contract benchmark. Benchmark provisions are often the subject of intense negotiation between the contracting parties, and understanding the value of specific benchmark provisions can inform both the client and the provider as to how to negotiate effectively. Figure 1 shows the optimal timing of the benchmark contract and the value of the across levels of  $\mu$  from -10 to 0, where  $T = 1$ . A value of  $\mu = -10$  with a contract length of  $T = 1$  is equivalent to a 10-year contract with -100% drift in price, so it seems like it is a reasonable boundary to the analysis.<sup>5</sup>

<sup>4</sup> According to PlanetMath ([www.planetmath.org](http://www.planetmath.org)), “Lambert’s  $W$  function is the inverse of the function  $f: \mathbb{C} \rightarrow \mathbb{C}$  given by  $f(x) := xe^x$ .  $W(x)$  is the complex-valued function that satisfies  $W(x)e^{W(x)} = x$  for all  $x \in \mathbb{C}$ . Lambert’s  $W$  function is sometimes also called [the] *product log function*.” See also Corless et al. (1996), and Agarwal et al. (2007) who used Lambert’s  $W$  in the case of mortgage refinancing decisions.

<sup>5</sup> To isolate the effects of the drift rate, and provide general interpretive results, in Figures 1 and 2 we plot the drift rate  $\mu$  assuming a contract length of  $T = 1$ . This allows any combination of contract length and drift rates to be calibrated to any time period considered by dividing the value of  $\mu$  where  $T = 1$  by the contract length. Thus, the absolute term  $\mu$

The y-axis represents both  $T$  and  $P = 1$ , as the upper curve represents costs and the lower curve represents prices. We can see that per the Optimal Benchmark Timing Proposition (P1), when the drift rate,  $\mu$ , approaches zero, the cost at the optimal benchmark nears  $P = 1$ . This implies no change in the market price, and as we discuss later, implies no benchmark. The optimal time to exercise the benchmark can be seen to approach  $t = .5$  as the drift rate  $\mu$  approaches 0, per Proposition 1. The value of  $P$  at the optimal benchmark can be interpreted as  $(1 - \%Cost)(Total\ Contract\ Costs)$ . Table 2 shows several contract scenarios for a given values of  $\mu$  and  $T$ .

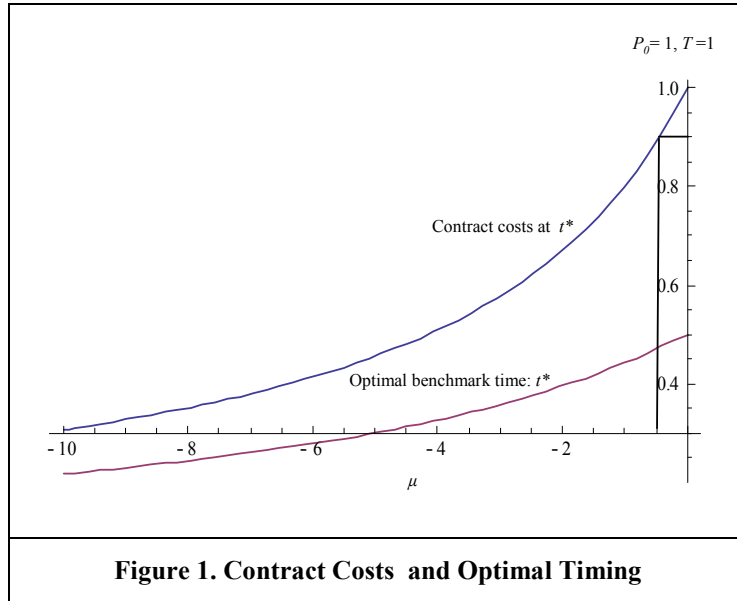


Table 2 calibrates several model input scenarios for given values of  $\mu$  and  $T$ .

<b>Table 2. Cost Savings Associated with Optimal Benchmarks</b>			
$T = 1$	Firm SLA Contract Cost	$T = 5$ Years	$T = 10$ Years
$\mu = -.5$	88.9%	$\mu = -.10$	$\mu = -.05$
$\mu = -1$	80.1%	$\mu = -.20$	$\mu = -.10$
$\mu = -2$	67.0%	$\mu = -.40$	$\mu = -.20$
$\mu = -4$	50.9%	$\mu = -.80$	$\mu = -.40$

**Note:** The left-most column represents values for drift rate  $\mu$ , where the contract length of 1 is assumed to be unit-less, which is consistent with the scale of Figure 3. The costs represent the percentage of the original contract costs which the client would pay if no benchmark took place. The two right-most columns show the implied drift rate and contract length associated with the optimal benchmark length.

Row 1 of Table 2 shows a five-year contract with potential cost savings of 11.09%. For a contract of \$1,000,000 dollars, that translates into a savings of \$110,900. For a \$20,000,000 contract, the benchmark provision is worth \$2,218,000. In other words, the larger the contract, the more valuable the benchmark is. Table 2 also shows the role of contract duration and drift rate of IT services costs in determining the timing

when  $T = 1$  can be calibrated across time periods and drift rates. For example,  $\mu = -1$  and  $T = 1$  represent the following drift rates and contract lengths: (a)  $\mu = -20\%$  in a five-year contract ( $T = 5$  years), or (b)  $\mu = -10\%$  in a ten-year contract ( $T = 10$  years). We will only use percentages to represent a special case of drift rates calibrated in the model. When  $\mu$  is not presented in terms of a percentage, we are referring to the drift rate where  $T$  is assumed to be 1.



and ultimate value of the benchmark decision. As the drift rate decreases and SLA delivery prices decline, we see that the contract savings increase. In this case, a client should benchmark earlier in the life of the contract, as shown on Figure 1. The client will reap more benefits at the earlier optimal benchmark time. More interesting is the effect of contract length on the benchmark value. As the contract length increases in the presence of a constant drift rate, the firm will benchmark earlier in the contract.

### ***Illustrative Example: A Case of One Benchmark***

To give the reader a feel for the kind of analysis we are proposing, we develop an illustrative example based on a scenario associated with the Gartner Group, as discussed in LeVasseur (2001). A Gartner client had a data center services outsourcing scenario where service prices were able to be evaluated based on the decline in *million of instructions per second* (MIPS) on a mainframe computer. By the time the client firm engaged Gartner, it was already six years into a ten-year contract, and the firm was paying well over double the market value of the services. Gartner estimated a 20% annual decline in the price of MIPS in the period from 1992 to 1998. In our model, a 50% decrease in market prices, as cited by Gartner, would occur at Year 6, in this case a drift rate of -11.5%. (The  $\mu$ -equivalent of -11.5% is -1.15.) We will consider both scenarios; together they provide useful intuition into measurement issues and the use of proxies in benchmarking. In Table 3 we compare the optimal solution implied by our model with the client's actual choice of benchmarking at Year 6 of the 10-year contract.

<b>Table 3. Value of Optimal Benchmarks</b>			
<b>Benchmark Strategy</b>	<b>Actual Drift</b>	<b><math>t</math> in Years</b>	<b>Firm SLA Contract Costs</b>
Implied drift optimal	$\mu = -11.5\%$	4.35	77.6%
MIPS drift optimal	$\mu = -20.0\%$	3.96	66.7%
MIPS drift optimal under implied drift conditions	$\mu = -11.5\%$	3.96	77.9%
$t = 6$ , implied drift	$\mu = -11.5\%$	6	80.1%
$t = 6$ , MIPS drift	$\mu = -20.0\%$	6	72.1%
<b>Note:</b> Firm SLA Contract Costs represent the percentage of contract value the firm pays under the benchmark strategy. The drift rate in IT service delivery cost is expressed in annual terms, with a 10-year duration. The left column shows the drift rates used to compute optimal time to benchmark.			

The scenario in which the client firm found itself paying twice the market rate in support of SLA costs appears in the 4<sup>th</sup> row for  $t = 6$  as the implied drift in Table 3. The client realized an 80% savings by undertaking the benchmark after the sixth year, based on the recalibration of the contract price with its vendor. Had the firm benchmarked at the optimal time (as shown in Table 3, Row 1), it would have saved an additional 2.4% of the total contract value, which may be a significant amount on a ten-year contract. Had the drift rate mirrored the mainframe MIPS price decline (as shown in the bottom row), then the firm would have saved 5.65% compared to its for the optimal time under the MIPS drift rate (as shown in Row 2). We can also see that had the firm applied the MIPS drift optimal rule for benchmarking (as in Row 3), then it would only have missed out on about .03% of the cost savings compared to the case where the client firm benchmarked at the optimal time. From this analysis, we can see that the benchmark model is fairly robust to changes in the drift rate when optimal conditions are applied.

### ***Benchmark Considerations with Transaction Costs***

In addition to understanding the optimal timing of the benchmark decision, it is useful to determine the conditions under which a benchmark should be considered. Specifically, we will look at what drift rate of the market price of IT services would need to be in the market before a benchmark would be undertaken.

The cost of the benchmark itself is expressed as  $X$ . Benchmark costs depend largely on the size of the contract. Most benchmarks cost \$100,000 but can run as high as \$1,000,000 according to Overby (2007a). Inserting the Optimal Benchmark Timing Proposition (P1) into the objective function gives the cost of the

contract at the optimal time of the contract. We then weigh the cost savings of the optimal benchmark versus the transaction costs,  $X$ .

- **Definition 1 (Cost Savings Threshold for Benchmarking).** *The client firm should only benchmark if the cost savings exceed the transaction costs of conducting the benchmark:*

$$P_0T - [P_0t^* + P_0e^{\mu t^*}(1 - t^*)] > X \quad (5)$$

The left-hand side of Definition 1 represents the cost savings, that is, the total costs with no benchmark less the total cost with a benchmark exercised optimally. If these savings exceed the transaction costs, then the benchmark should be considered. Figure 1 shows the relationship between contract costs, optimal timing and the drift rate of expected market prices. The value for  $t^*$  approaches .5 (the halfway point of the contract) as  $\mu$  approaches 0 (which is a neutral drift rate), as we noted ought to be the case in the Optimal Benchmark in the First Half of the Contract Proposition (Proposition 2). The transaction costs,  $X$ , are represented on the price axis labeled  $P$ . The intersection of the horizontal line drawn from  $X$  to the drift axis (labeled  $\mu$ ) implies a maximum value for  $\mu$  of the expected drift rate of IT services prices where the benchmark should take place. As shown in Figure 1, the benchmark would cost 10% of the total contract value. In order for the benchmark to even be considered, the firm would need to expect a drift rate less than or equal to  $-.5$ . Consider the following calibration of a small contract for 5 years with an annual payment of \$120,000. The firm would be looking at paying \$60,000 (10% of the total contract value of (\$600,000) for a benchmark. For the benchmark to be profitable, the firm needs the market price to decline by 10% per year. That may be a reasonable assumption, but nevertheless it is something the manager must consider when making a decision to exercise the benchmark option.

## Volatility in Expected Drift Rate

A fair question at this point is for the reader to ask: if IT service prices are expected to decline at a known rate when the contract is signed, why wouldn't the parties simply negotiate a price schedule to reflect that known drift rate? Per our motivation in the beginning of this paper, we know this is not the case. At best, firms can make reasonable approximations of the expected drift rate, but these approximations will be subject to uncertainty regarding technology cost competition over time. Consistent with investments under uncertainty modeling conventions that we have already outlined, we consider uncertainty as risk in terms of geometric Brownian motion, as it is often portrayed in financial economics models. This implies that the realized drift rate will follow a normal distribution around the mean of the expected drift rate.

### Uncertainty Trade-Offs with Benchmarking

We model the effects of uncertainty with two issues in mind. First, we consider the potential gain if the client were to gamble and exercise the benchmark at the optimal time, given a scenario of rapidly decreasing costs of the IT services that underlie the SLA contract. We also compare this to the value of the optimal timing decision under different drift rate scenarios. We represent uncertainty trade-offs with a simple rule devised from the definition of the Cost Savings Threshold for Benchmarking (D1):

$$\Pr[\mu' < \mu][P_0t'T + P_0e^{\mu'i'T}(T - t') - P_0t^*T + P_0e^{\mu'i^*T}(T - t^*)] > [P_0t^*T + P_0e^{\mu'i^*T}(T - t^*) - P_0t'T + P_0e^{\mu'i'T}(T - t')] \quad (6)$$

Here  $t'$  is the optimal timing at  $\mu'$ , and  $\mu'$  represents a given quantile of the drift rate  $\mu$ .  $\Pr[\mu' > \mu]$  represents the probability that the actual drift rate  $\mu$  is greater than  $\mu'$ . See the Appendix for a derivation.

The first term in Equation 6 represents the expected value of the difference between choosing the optimal benchmark under the scenario where prices are rapidly decreasing – in other words, a more negative value of  $\mu$  – weighted by the probability, versus choosing the optimal benchmark with no uncertainty. Table 4 shows the effects of volatility on the benchmark strategy. We infer the probabilities from quantiles of the normal distribution, corresponding to the standard deviation of our stated pricing dynamics (Equation 1).

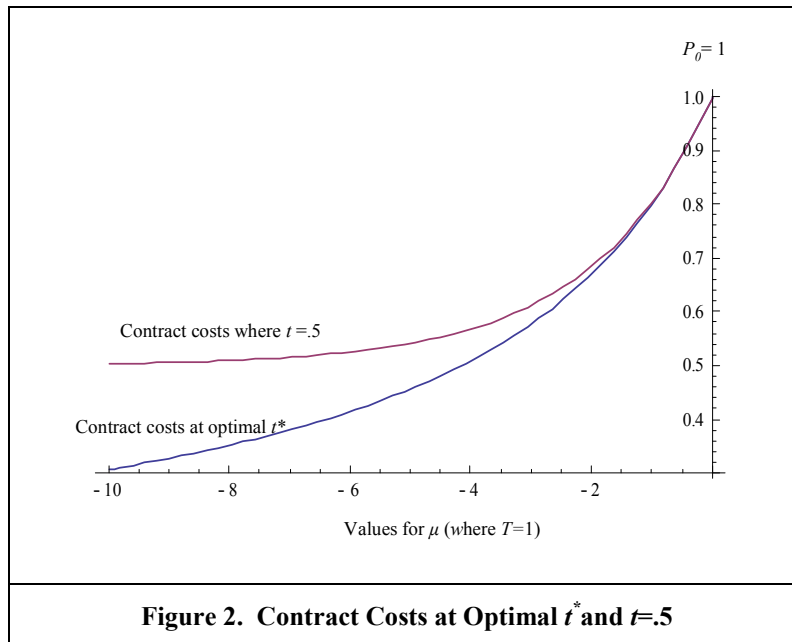
In the table below, we calibrate the model such that the firm faces the same expected drift rates in the costs of MIPS as in the earlier example, where the drift rate was  $-20\%$ . This time we include a volatility of  $\sigma =$

.35 surrounding the drift. This represents the uncertainty associated with the client firm’s forecast of prices. (Here, there is a two-thirds likelihood that the price will go 35% above or below the mean.) The first row illustrates a strategy in which the firm optimizes for the 90<sup>th</sup> percentile of the expected drift rate. With this strategy, the firm will only end paying 35.55% of the original contract costs. Thus, the firm has a 10% chance of saving an additional 35% of total contract costs, as compared to the scenario where IT service prices decline by 20%. However, as the third row shows, if the firm benchmarks according to the strategy where the IT service costs decline by 20% when the drift is actually -78.5%, the firm will realize a cost saving of 42.31% of total contract costs. The firm still reaps significant savings. If drift rate at the 90<sup>th</sup> percentile is -78.5%, then the client will forgo about 4% of expected cost savings. When the savings are weighted for probability, the firm is better off staying with the optimal strategy, where  $1(42.31 - 35.55) = .676 < 70.68 - 66.96 = 3.72$ .

Table 4. Volatility Effects on Benchmark Strategy		
Optimize According to Drift at:	Actual Drift	Firm SLA Contract Cost
At 90 <sup>th</sup> percentile = -78.5%	-78.5%	35.5%
	-20.0%	70.7%
For a 20% IT service cost decline	-78.5%	42.3%
	-20.0%	67.0%

**Note:** Firm SLA Contract Cost represents the percentage of contract value the firm pays under the benchmark strategy. The *drift rate* is expressed in annual terms, with a duration of 10 years ( $T = 10$ ). The left column shows the drift rate in IT service prices under which the firm chooses the optimal time to benchmark.

Figure 2 compares an optimal strategy where the expected drift rate is zero ( $t = .5$ ) to optimal strategies at hypothetical drift rates of IT service prices.



The upper curve in Figure 2 demonstrates the contract costs when  $t = .5$  across all possible scenarios of service price declines in the interval  $-10 \leq \mu \leq 0$ , when  $T = 1$ . The reader should recall that the drift rate  $\mu$  can be presented in a general, although it can be calibrate as a IT service price decline percentage for any contract length. The bottom curve represents the costs of a contract when optimized according to the Opti-

mal Benchmark Timing Proposition P1 at every instance of  $\mu$ . At drift rates near zero, the contract costs are nearly identical. As the drift rates go more negative there may be a benefit to benchmarking earlier in the period.

There is little difference between the two approaches until the drift rate of IT services prices goes well below -2. Note from Table 2 that  $\mu = -2$  implies a 20% annual rate of IT service price decreases in a 10-year contract in the market. In a 5-year contract, this represents a 40% annual rate of decline over 5 years. One can draw the conclusion that in short contracts, with relatively high rates of forecasted price declines, a firm may do well to benchmark at  $t = .5$ . As the drift rate and duration of the IT service contract decrease beyond  $\mu = -5$ , we see substantial potential savings.  $\mu = -5$  implies an annual decline in prices of 100% for 5 years, 50% for 10 years, or 25% for 20 years, depending upon the contract length. While unlikely, in this scenario, benchmarking at the half-way point involves missing out on savings of about 9% of total contract value. The client is better off choosing the optimal solution according to their forecast of IT services prices.

### ***Volatility Considerations with Near Zero Drift Rates for IT Service Costs***

We observe from Figure 2 that the client's choice of benchmark timing should be insensitive to the drift rate in terms of overall IT service costs. This fact can be leveraged by providers to benchmark even when the expected drift rate is at or near zero. Since benchmarking contracts almost always trigger downward price adjustments, client firms do not face a downside risk of a price increase. When the drift rate is zero, the optimal choice is not to benchmark. Because of volatility in the drift rate, the firm can exercise the benchmark to benefit from potential prices decreases. The benefit the firm receives is similar to holding a call option. This option gives the client the right to receive lower IT services pricing at a date of their choosing. However, the client is not obligated exercise the option if the market price is higher than the price specified by the benchmark. The only downside exposure is the transaction costs. We define the conditions of benchmarking with modest expected price declines – in other words, a near-zero drift rate for IT service costs – and volatility considerations in Definition 2:

- **Definition 2 (Benchmark with Near-Zero Drift Rates and Volatility).** *If the cost savings associated with the benchmark do not exceed the transaction costs,  $X$ , but there is a chance of SLA price declines, the firm should benchmark at  $t = .5$  if the probability weighted cost savings exceed the transaction costs:*

$$P_0 T - \Pr[\mu' < \mu][.5P_0 + .5P_0 e^{\mu'.5}](.5P_0 + .5P_0 e^{\mu.5}) > X \quad (7)$$

where  $\mu'$  implies a value for drift rate of IT service costs at a specified confidence level, and  $\Pr[\mu' > \mu]$  represents the probability that the actual drift rate  $\mu$  is greater than  $\mu'$ .

The inner term on the left side of Equation 7 is derived by inserting  $t = .5$  for  $t^*$  in Equation 5. From Figure 2, we can see that if a client firm projects a 50-50 chance of a modest degree of decline in IT service price drift of  $\mu - 1$  ( $T = 0$ ), benchmarking at  $t = .5$  yields a potential cost savings of 10%. Only 5% would be expected with a probability of less than 50%. If the benchmark costs \$100,000, then the firm should invoke it at  $t = .5$  if the total contract value exceeds \$2,000,000.

For shorter contracts and moderate expected SLA price declines, benchmarking at the halfway point provides a satisficing solution. In situations where the client has little information to make projections of the expected drift rate, a strategy of benchmarking at the half-way point in a contract can offer significant benefits while limiting the downside risk of not meeting a benchmark threshold. This can happen if the firm benchmarks too early in the contract.

## **Multiple Benchmarks within a Contract**

Heretofore we have only considered the case of one benchmark provision in a contract. In practice, clients often request multiple benchmarks over the contract duration. The issue of benchmark frequency is a common subject of contention in negotiations between clients and providers, according to Overby (2007a). In this section, we extend our baseline model to account for the possibility of two benchmarks over the duration of the contract and compare the results to the case with one benchmark. We examine conditions under which a client firm chooses a single-benchmark versus two-benchmarks ( $t_1, t_2$ ), with the following objective function:

$$\underset{t}{\text{Min}} C = P_0 t + P_0 e^{\mu t_1} (t_2 - t_1) + P_0 e^{\mu t_2} (T - t_2) \tag{8}$$

**Illustrative Example: A Case with Two Benchmarks**

In the case of two benchmarks the firm must chose optimal  $t_1^*$  and  $t_2^*$  to minimize the total cost over both periods. The contract with provisions for two benchmarks can be thought of as consisting of three periods. Initially, the client pays the original price agreed to in the IT services contract, which is seen in the first term of Equation 8. The second term represents the period where the first benchmark prices prevail. The last represents the third period, where the client pays the price identified by the second-period benchmark.

We do not consider a closed form solution for the two-period case. We apply backwards induction to solve for the optimal benchmark schedule  $(t_1^*, t_2^*)$ . To solve the optimal benchmark schedule we consider the cost intervals separately. We first calculate second period costs, given by the last two terms in Equation 8:

$$C(t_2) = P_0 e^{\mu t_1} (t_2 - t_1) + P_0 e^{\mu t_2} (T - t_2) \tag{9}$$

We select a candidate value of 0 to  $t_1$ , which we denote as  $t'_1$  equal to zero. With this candidate we define an optimal value for  $t_2$ , which we denote as  $t'_2$ . We apply the same technique and refer back to the proof for the Optimal Benchmark Timing Proposition (P1) to solve for an optimal  $t'_2$ , given a candidate value  $t_1$ :

$$t'_2 = \frac{\mu T + W(e^{1-\mu T + t_1 \mu}) - 1}{\mu} \tag{10}$$

We then insert  $t'_2$  into the objective function defined in Equation 8 for a total cost at  $(t'_1, t'_2)$  of:

$$C(t'_1, t'_2) = P_0 e^{\mu t_1} \left( \frac{\mu T + W(e^{1-\mu T + t_1 \mu}) - 1}{\mu} - t_1 \right) + P_0 e^{\frac{\mu T + W(e^{1-\mu T + t_1 \mu})}{\mu}} \left( T - \frac{\mu T + W(e^{1-\mu T + t_1 \mu}) - 1}{\mu} \right) \tag{11}$$

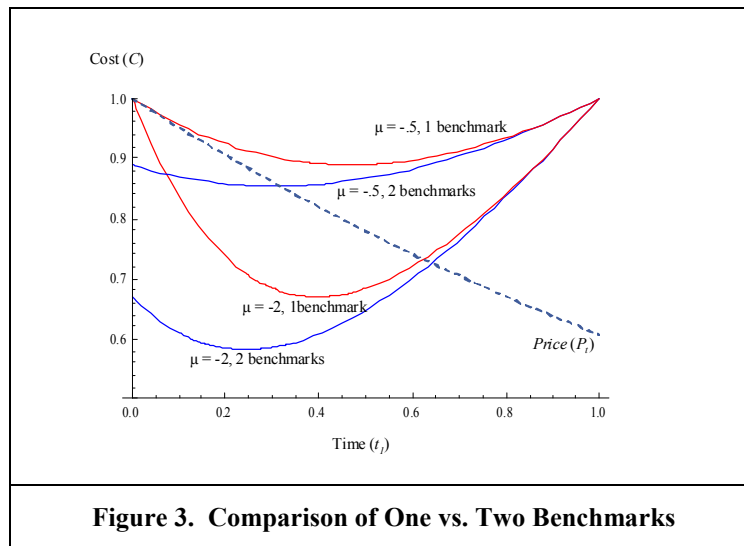
On the first iteration, if we consider the period one benchmark candidate,  $t'_1$  equal to 0, the  $t'_2$  value will be equal to the optimal one-period benchmark. From this point, the solution is iterated until an optimal benchmark schedule  $(t_1^*, t_2^*)$  is identified. Consistent with the single-period benchmark, the optimal time to the first benchmark,  $t_1^*$ , increases as the value for  $\mu$  and  $T$  increase. See Table 5.

Table 5. Optimal Timing and Value of Two Period Benchmark						
$\mu$ ( $T = 1$ )	Two-Period Benchmark		One-Period Benchmark			
	$T^*_1$	$t^*_2$	Firm SLA Contract Cost	$t^*_{\text{One\_Benchmark}}$	Firm SLA Contract Cost	Difference
-0.5	.31	.64	85.41%	.47	88.90%	3.49%
-1.0	.28	.61	74.16%	.44	80.01%	5.85%
-2.0	.24	.56	58.15%	.40	66.95%	8.80%
-4.0	.21	.48	40.20%	.33	50.89%	10.79%

**Note:** The Firm SLA Contract Cost represents the percentage of contract value the firm pays under the benchmark strategy. The left column shows the drift rate in IT services costs,  $\mu$ , where  $T = 1$ .

Table 5 shows the relationship between the single-benchmark and the two-benchmark contract cases. As the drift rates of IT service prices in the market nears zero, the difference in cost savings between the two approaches narrows for the client. Two-benchmark strategies are more valuable as the drift rate in IT service prices decrease. For example, Row 1 shows a contract with a drift rate in the IT services price of  $\mu = -.5$ , which is equivalent to a 5% price decline over a ten-year contract. Depending on the total costs of the benchmarks, a firm may find the additional 3.49% savings over the contract life an insignificant amount. For a large contract this might make sense, however, in smaller contracts, the cost of the benchmark could easily exceed the expected gains. At lower drift rates of IT services prices, the differences are more pronounced, as Rows 3 and 4 illustrate. Row 2 represents the 20% price decline that we used in the earlier MIPS case. In this example, the client would have realized close to 5.85% cost savings over the total contract, which would likely be significant in a multi-year data center outsourcing scenario.

Figure 3 graphically compares the one- and two-benchmark scenarios. The figure plots the total costs as a proportion of the contract value on the vertical axis, and the time to the first benchmark on the horizontal axis. The two curves which intersect at  $C = 1.0$  represent the single-benchmark scenarios. The curves which intersect where  $C = .89$  and  $.67$  represent the two-period benchmark at  $\mu = -.5$  and  $-2$ , respectively. If the first benchmark is not undertaken, the second benchmark collapses to the single-benchmark optimum. The optimal total costs can be inferred from the lowest cost point which the curves reach, and we note that the cost differences can be seen to increase as the drift rate for the IT services price moves from  $-.5$  to  $-2$ . From our earlier discussion of benchmark timing, we see that, as intuition suggests, multiple benchmarks will be most useful in situations where the duration is longer.



**Figure 3. Comparison of One vs. Two Benchmarks**

### ***Benchmark Threshold and Multiple Periods***

With downward future adjustment of prices, benchmark provisions cut into the profits of the service provider. Providers often claim that the benchmarks do not accurately reflect the market price of services (Harris 2007a). To shield themselves against this uncertainty, service providers often insist upon a reasonable discrepancy between the price identified in the benchmark and the current price of the contract. A common tool is a *pre-identified threshold* that must be met, usually 10% or 15% before price adjustments take place. Therefore, the providers are shielded against any downward bias in the benchmark sampling data.

The dashed line in Figure 3 represents the prices over the interval  $0 \leq t \leq 1$ , where  $P_t = P_0 e^{\mu t}$ ,  $P_0 = 1$ , and  $\mu = -.5$ . If the benchmark threshold were set at .80, the first-period benchmark would result in no price adjustments since the price of the IT services is equal to .85. However, the price at the single-benchmark optimum is .79. This illustrates a case where a provider can benefit by granting the client firm the option to benchmark twice, but negotiate a higher threshold for price adjustments.

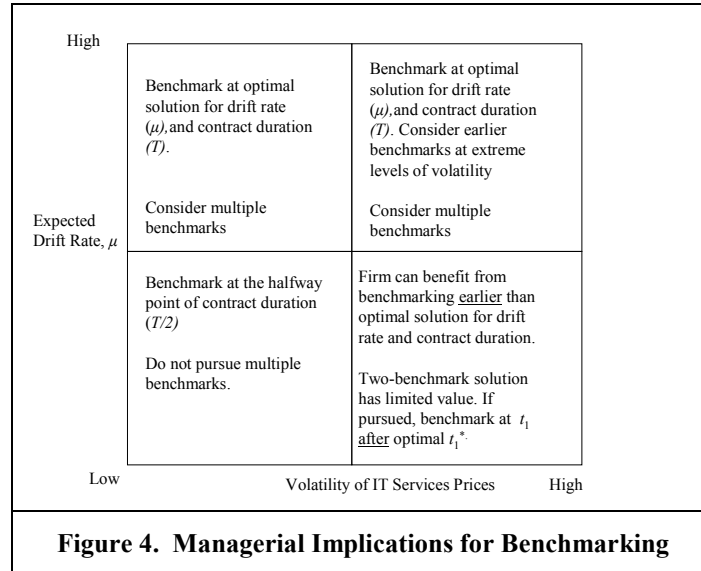
The benchmark threshold is especially interesting given situations of uncertainty around the expected drift rate of market prices for IT services or the accuracy of the benchmark. It adds the possibility of potential losses for the firm when it exercises the benchmark. If the threshold is not met, the client risks losing the investment costs associated with the benchmark. If there is significant volatility and the drift rate is relatively close to zero, a client may insist on a two-benchmark provision, but conduct the benchmark at a later date than the optimal  $t_1^*$ , where there is more certainty that the cost savings threshold may be met, while still benefiting from a second benchmark.

### **Managerial Implications**

Our approach gives useful insight for managers. Recall that our model assumes an exponential drift rate for the market price of IT services, so its implications for practice are not generalizable. Several other drift rate scenarios for IT services prices could be modeled with different shapes over time, including the possibility

of delayed diffusion of services or market shocks. With those caveats acknowledged, we summarize our findings in Figure 4.

One of the main findings of this research is that our exponential model is quite robust to volatility in the estimates or the drift rate of IT service prices. When the volatility of the expected decline in IT prices is high, the effects of benchmarking early to leverage volatility are minimal. Even if the drift rate is lower than expected, the firm still benefits substantially from benchmarking at the optimal point according to the forecast for IT service prices. The more intriguing example is shown in the lower left box. Client firms can leverage the fact that benchmark provisions do not expose them to the downside risk associated with a price increase. Therefore, like an option, the client firm’s financial exposure is limited to the transaction costs and the threshold set by the provider.



When the expected drift rate of IT service prices is near zero, multiple benchmarks have limited value. Volatility may influence the decision to pursue multiple benchmarks in the contract. We find that the first benchmark in a two-benchmark contract should be earlier than in the single-benchmark case. Under modest expected declines in the price of IT services, this could expose the firm to benchmarking when the price does not meet the threshold of cost savings. To remedy this exposure, the client can exercise the first-period benchmark later in the contract. This gives the client greater confidence in meeting the price thresholds while still creating benefits from the two-period benchmark.

## Conclusion

### Contributions

We developed a new model to quantify the value of benchmarking strategies for IT services contracts. We devised a method for setting benchmark timeframes *a priori* under conditions of opaque market pricing. Our model considers a unique financial instrument: *IT services price benchmarks*. While our model shares characteristics of mortgage refinance and credit risk models from financial economics, to our knowledge, there has been no prior work evaluating benchmarking intervals with opaque pricing, and hence our analytic model makes a unique contribution to the literature.

We modeled the effects of uncertainty in the drift rates of IT service prices, and showed that a firm can leverage the option value of exercise benchmark provisions that would have been forgone when the drift rate of the price of IT services is near zero. We extended our model to two periods and saw that a client firm is better off considering the two-period model, except when the rate of decrease in expected market prices for IT services is modest – not so large that it causes substantial cost changes. We demonstrate how provider firms can leverage this model to negotiate thresholds at which price adjustments are made after comparison with market prices for IT services identified by the benchmark. We also showed how our re-

sults can influence managerial decision-making, especially when managers are aware of the value of collecting this kind of data in support of contract management.

There may be policy implications regarding the benchmark provisions and strategies. An analogy can be drawn to *price-matching guarantees*, whereby a firm offers to match competitors pricing. There is ongoing debate over whether this leads to anti-competitive behavior, because firms may have no incentive to lower prices under such provisions (Edlin 1997, Corts 1995). In our model, we have assumed that market prices are exogenous, but it is possible that benchmarking could serve as an incentive for provider firms not to lower prices. Future research could develop incentive compatible mechanisms which facilitate information sharing among client and provider firms, and which will lead to the most competitive outcome. ....

### **Limitations**

This initial work is subject to several limitations. First, we have conducted a financial analysis of benchmarking provisions for IT outsourcing contracts. There are several non-quantifiable factors that need to be considered before a firm exercises a benchmark though. Clients and providers with a high level of trust may be able to accommodate price adjustments without going through a formal benchmarking process, saving money along the way. The benchmarking process is often contentious and there are hidden costs associated with loss of goodwill between the parties when a benchmark is conducted. Client firms must realize that it is in their long-term interests to have providers who earn reasonable profits.

On the modeling side, we assumed a constant exponential drift rate for IT service prices. This was a reasonable starting point in the analysis since the assumptions are consistent with other asset pricing and investment under uncertainty models on which our theoretical perspective is built. Moore's (1965) law provides some validation that computing costs have followed an exponential drift pattern. We expect IT services prices may follow other distributions. An intriguing possibility is that IT services may follow a Bass (1969) diffusion, where competition and innovation affect adoption, and thus market prices for the IT services. We are likely to run into issues with data availability. Likely sources are outsourcing providers or benchmarking firms. In either case, researchers will need to work with a snapshot of the market data. The question of *generalizability* will arise from empirical work based on this model.

We model the volatility of market prices with the geometric Brownian motion diffusion process. We can relax the assumption of normal distributions to fit other distributions of pricing dynamics. Value-at-Risk approaches provide guidance for such adjustments (Jorion 2006). *Conditional value-at-risk* models are often used to alleviate the issue of kurtosis and skewed distributions. Also, a *quantile-based value-at-risk* model can be build by bootstrapping available historical data (Jorion 2006). *Extreme value theory* is another approach that has been applied to model extreme quantiles in a value-at-risk context (Bekiros and Georgoutsos 2005, Gencay and Selcuk 2004). Another possibility is to consider technical or service operation innovations that arrive via a Poisson distribution, which leads to radical reductions in market price.

### **Future Research**

This work represents an initial attempt at financial analysis of IT services contract benchmarks. We will extend the work analytically and empirically. A major issue that separates IT services contracts from others is the availability of accurate benchmark prices. We will explicitly consider the availability of market pricing information in our model and the associated effects on competition. As we mention earlier, we believe that a key extension will occur in the design of effective incentive-compatible mechanisms which will ultimately lead to better contractual provisions for both providers and clients.

We will also consider the service life-cycle in future work. We are interested in the effects of economies of scale and scope on services pricing and the benchmark process. Provider firms often initiate large contracts with clients with the hopes of replicating the services across a broad customer set. As these services diffuse through the market place, competition may arise to erode profits, not only for new customers, but among the "beachhead" clients where the provider firm presumably can earn high margins due to innovation. This analysis will help quantify some of the effects of a replication strategy by IT service innovators.

We will extend this work to develop predictive models of IT services pricing and diffusion. This empirical



work will allow us to extend the value of information analysis of IT prices in the context of forecasting and benchmarking. In addition, an algorithm-based optimization model can provide insights into the optimal number of benchmark provisions a client would wish to include in a contract. This analysis also can offer useful information for provider firms in negotiation for multiple benchmark provisions.

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## Appendix: Deriving a Decision Rule for Benchmarking under Uncertainty

Equation 6 gives a decision rule for exercising the benchmark under conditions of uncertainty. We compare the differences in total costs of benchmarking according to two distinct scenarios of IT services price drift,  $\mu'$  and  $\mu$ .  $\mu'$  represents a drift rate which occurs with a small probability, and  $t'$  represents the optimal time to benchmark according to this drift rate.  $\mu$  represents the expected or mean drift rate of IT services pricing, and  $t^*$  represents the optimal timing for  $\mu$ .  $[P_0 t' T + P_0 e^{\mu' t' T} (T - t') - P_0 t^* T + P_0 e^{\mu t^* T} (T - t^* T)]$  represents the differences in the costs of the two strategies if  $\mu'$  occurs. The second comparison occurs when the expected drift rate  $\mu$  occurs:  $[P_0 t^* T + P_0 e^{\mu t^* T} (T - t^*) - P_0 t' T + P_0 e^{\mu t' T} (T - t')]$ . Note that the two mathematical expressions are the same, except for the drift rates  $\mu'$  and  $\mu$ . Finally, we weigh the first expression, the probability that  $\mu'$  will be realized, and compare the values for the two scenarios to yield Equation 5.