European Journal of Operational Research 219 (2012) 272–283

Contents lists available at SciVerse ScienceDirect

European Journal of Operational Research

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

Production, Manufacturing and Logistics

Impact of sourcing flexibility on the outsourcing of services under demand uncertainty

Michel Benaroch [1], Scott Webster *, Burak Kazaz [2]

Whitman School of Management, Syracuse University, 721 University Avenue, Syracuse, NY 13244-2450, United States

ARTICLE INFO

Article history:
Received 15 August 2011
Accepted 5 December 2011
Available online 13 December 2011

Keywords:
Services outsourcing
Backsourcing
Demand uncertainty
Real options

ABSTRACT

This paper investigates the relationship between market conditions and the value and use of sourcing flexibility for service processes. We develop and analyze a series of models, and we derive expressions for the optimal switching decision, the value of the option to outsource, the value of the option to backsource, and the probability and timing of switches between the alternative sources.

One contribution is the models and associated derivations, which are largely new to the literature and may serve as a tool to support service sourcing plans and decisions. The second contribution is a series of results with managerial implications: (1) The probability of outsourcing is generally increasing in volatility for high-skill process and decreasing in volatility for low-skill processes. Earlier work has found that the hysteresis band is increasing in volatility, which is interpreted as an indicator of increasing organizational inertia. We also find that the hysteresis band is increasing in volatility, but interestingly for the case of high-skill processes, organizational inertia tends to be decreasing in volatility. (2) The option to backsource is generally more valuable for high-skill processes than for low-skill processes. This result suggests that investments to make it easier to backsource should have a higher priority for high-skill processes. (3) The value of the option to backsource a high-skill service process can be decreasing in volatility. The result suggests that a rather nuanced consideration of volatility is in order when considering investments in the flexibility to backsource a high-skill process.

1. Introduction

Much research has focused on manufacturing outsourcing, but today attention is shifting towards the outsourcing of service processes (Ellram et al., 2008; Hutzschenreuter et al., 2011). The operating implications of services outsourcing may be more subtle than manufacturing outsourcing. Services are characterized by: intangibility, perishability (i.e., cannot be stored), simultaneity and inseparability of production and consumption, and higher customer contact (Spohrer and Maglio, 2008).

Of particular interest to us is the outsourcing of transaction-based, information-intensive service processes with volatile demand. Specifically, we consider a firm that is currently insourcing such a service process and has the option to outsource the process. The operating cost structure comprises a fixed cost per period and variable cost per transaction. In insourcing, the fixed cost per period is associated with overhead for salaries, personnel training, and other infrastructure resources, such as office space, software licenses, hardware leases, data centers, and software updates for changing business and compliance requirements (SAP, 2006). In outsourcing, the fixed cost per period is associated with monitoring vendor performance, service quality and regulatory compliance, with using secured high-capacity telecom connections to transaction exchanges, and with ongoing maintenance and updates of retained inter-dependent processes and interfaces in response to vendor-initiated changes to the outsourced process (SAP, 2006); it may also include a per-period fee charged to the firm by the vendor (Miriyala and Gurbaxani, 2005). Fixed costs per period are not considered in many earlier studies even though they are a crucial element in the cost structure of real-world service processes (SAP, 2006; Aggarwal et al., 2007). Capacity considerations, on the other hand, are of lesser concern due to the employment of usage-based pricing and scalability of information technologies; this is clearly stated in Miriyala and Gurbaxani (2005, p. 5): “The client is able to buy capacity as and when needed without incurring high fixed costs. The vendor is able to spread its investment cost by scaling the delivery platform to multiple clients that need the same kind of service.”

Like with manufacturing outsourcing, among the most cited reason for outsourcing service processes is cost reduction (Miriyala and Gurbaxani, 2005). For service processes that face volatile demand, the cost reduction is primarily due to the ability to change

* Corresponding author. Tel.: +1 (315) 443 3460.
E-mail addresses: mbenaroc@syr.edu (M. Benaroch), stwebste@syr.edu (S. Webster), bkazaz@syr.edu (B. Kazaz).
[1] Tel.: +1 (315) 443 3492.
[2] Tel.: +1 (315) 443 7381.

0377-2217/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.ejor.2011.12.007

the cost structure – by turning fixed costs into variable costs – combined with the ability to meet flexible capacity needs.

Despite the benefits, though, cost reduction expectations are not always met (Ren and Zhou, 2008; Wentworth, 2008), and the proportion of firms that decide to backsource is growing despite contract termination penalties and the costs of bringing a process back in-house (Wentworth, 2008; Whitten and Leidner, 2006; Veltri et al., 2008). Examples are abundant, including a number we will elaborate on later, such as Dell and Lehman Brothers' call center operations (Ren and Zhou, 2008) and a major unnamed health insurer's data entry operations (Gingrande, 2005).[3] A study of tens of cases found the reasons for backsourcing to center around high indirect costs and strategic considerations (Veltri et al., 2008). Indirect costs are due to errors, remedial work on problem transactions that must be located and fixed in-house, unsatisfied customers, and reputational damage. Strategic considerations pertain to the loss of expertise and tacit knowledge necessary to control the outsourced services (Tiwana and Keil, 2007; Layne and Green, 2011) and the loss of innovation in service operations (Gray et al., 2009; Amaral et al., 2006; Takeishi, 2001).

Concerns over indirect costs and strategic considerations motivate firms to reserve the flexibility to backsource an outsourced process (Tan and Sia, 2007; Wentworth, 2008). Reserving this flexibility, however, goes well-beyond adding a clause in the outsourcing contract. It requires retaining the management of the process along with the necessary expertise. The firm has to keep in-house a group of experts and qualified personnel who can develop and maintain control processes for monitoring and benchmarking the vendor's work and, more importantly, for ensuring ongoing learning for continued process improvement and innovation (Ellram et al., 2008; neoIT, 2004). Emphasizing strategic considerations in backsourcing, Charlene Begley, the chief information technology officer of GE, states the following: "About 50% of the IT work was done by non-GE employees. That strategy may have had its time, but there was a lot of downside. We lost a lot of technical capabilities we have to own" (Layne and Green, 2011).

How does the decision to reserve the flexibility to backsource impact the decision to outsource in the first place is a question that has not been addressed in the literature. Earlier research offers valuable insights into the outsourcing decision primarily in the manufacturing context; however, it is not clear how well these insights extend to the outsourcing of services. In manufacturing settings, capacity issues are of primary concern, however, these studies ignore the influence of fixed costs per-period in outsourcing decisions (Lu and Van Mieghem, 2009). More relevant is work in real options theory (Dixit, 1989a,b; Dixit and Pindyk, 1994), and particularly Kogut and Kulatilaka (1994) and Kouvelis et al. (2001) who treat the flexibility to outsource as a real option and study the boundary demand condition at which it is optimal to switch to outsourcing. The primary finding in these studies is that increasing demand volatility increases both the value of the option to outsource and the hysteresis band defined by the optimal boundary conditions for switching to outsourcing. This finding implies that the firm has a greater tendency to outsource when demand volatility grows. However, it is not clear whether this finding extends to the outsourcing of services, especially when the firm reserves the flexibility to backsource.

This paper builds on the above research and extends real option models for finding the optimal demand thresholds for making a switch to outsourcing modes in three directions. We develop and analyze a series of models that incorporate changing and uncertain transaction volume over time, insource and outsource fixed and variable costs, the cost to switch to outsourcing, and the cost to bring a service process back in-house. Firstly, we introduce models of two dual situations, termed *Regime 1* and *Regime 2*, in which the question of if and when to outsource arises since no sourcing mode offers an absolute cost advantage. Under Regime 1 the outsourced variable cost (per transaction) is higher than the insourced variable cost, and the outsourced fixed cost (per period) is lower than the insourced fixed cost. Sample services that fit this regime are high-skill services such as telemedicine and software development. We use later teleradiology to illustrate what happens in Regime 1. Under Regime 2 the outsourced variable cost is lower than the insourced variable cost, and the outsourced fixed cost (per period) is higher than the insourced fixed cost. Sample services that fit this regime are low-skill services such as call centers, claims processing, and data entry. We use later data entry and call center to illustrate what happens in Regime 2.

Secondly, we derive the optimal demand threshold for switching to outsourcing, the value of the option to outsource, the probability of outsourcing, and the expected time to switch to outsourcing. Since it takes time to switch to outsourcing (vendor search, contracting, transition, etc.), a decision to outsource ought to be reached before actual demand hits the optimal threshold. Hence, it is important to know the probability that the threshold will be reached, conditional on the demand level observed at the decision point; unless this probability is reasonably high, the expected time for demand to hit the threshold is infinitely long. It is important to note that no earlier study has examined the probability of hitting the optimal boundary demand values for outsourcing. Alvarez and Stenbacka (2007), for example, only characterize the sign of expected time of hitting the optimal demand threshold as a function of demand volatility.

Thirdly, we characterize how upfront consideration of the flexibility-seeking strategy of backsourcing impacts the probability of making a decision to switch to outsourcing in the first place, as a function of demand uncertainty and relative differences in sourcing costs. In so doing, we seek to check whether increased sourcing flexibility necessarily translates into increased likelihood of outsourcing.

We start by developing and analyzing base models for outsourcing the service process without the flexibility to backsource in midstream. The base model and all associated derivations for Regime 1 are new to the literature to our knowledge. The base model of Regime 2 yields known results on boundary conditions for outsourcing and the expected time to outsourcing but includes a new result that gives the probability of outsourcing. In order to tighten the focus of our results, we concentrate our interpretations on a setting where long-run transaction volumes are expected to be flat or increasing over time – a setting likely to have wider relevance due to population growth in practice, compared to declining markets. We find for both Regime 1 and Regime 2 that increasing demand volatility increases the value of the option to outsource and the hysteresis band defined by the optimal boundary conditions for switching to outsourcing, like in Kogut and Kulatilaka (1994) and Kouvelis et al. (2001). But, we also find that the probability of making the switch depend critically on the cost structure of the regime. Under Regime 1, increased demand volatility generally increases the probability of making a switch to outsourcing. By contrast, under Regime 2 the exact opposite is observed: increased

[3] Backsourcing is clearly evident among businesses that outsource information technology (IT) services. Deloitte Consulting reported that nearly two-thirds of organizations have brought some forms of outsourced service back in-house (Samuels, 2005). Gartner Group reported that 56% of small-sized business and 42% of mid-sized business contracts are backsourced following contract discontinuance (Brown, 2004). SAP INFO Solutions reported that 20–30% of all business process outsourcing contracts are terminated within two years and 80% need to be renegotiated (Bloch and Spang, 2003; Mani et al., 2005). Diamond Cutter reported that about half of all IT outsourcing contracts are terminated or renegotiated within the first year (Weakland, 2006). These reports are consistent with figures reported by earlier academic studies (Fitzgerald and Willcocks, 1994; Lacity and Willcocks, 2000; Barthelemy, 2001).

demand volatility generally decreases the probability of making a switch to outsourcing. The result suggests that it is important for managers to account for the nature of the cost structure when considering how the attractiveness of outsourcing changes under scenarios of future high or low volatility.

We then expand the base models to examine the impact of incorporating backsourcing flexibility, that is, the flexibility to bring an outsourced process back in-house. The backsourcing models and associated derivations are new to the literature. We find that the inclusion of backsourcing flexibility never decreases the probability of a switch to outsourcing. This is a robust result as it holds under both regimes, where the outsourcing alternative has either a fixed-cost or a variable-cost advantage. More importantly, we also find that the value of the option to backsource is generally higher in Regime 1 than in Regime 2, indicating that investments to make it easier to backsource should be a higher priority under Regime 1. Finally, contrary to conventional wisdom we show that the value of including backsourcing flexibility in the outsourcing arrangement can be decreasing in demand volatility under Regime 1. In essence, we find that as volatility increases, the risks associated with service obsolescence in a high-skill process can dominate the value of the flexibility to bring a process back in-house. The result implies that it is less important for firms to build backsourcing flexibility for outsourced processes with a highly volatile demand than it is for processes with less volatile demand. These are novel results that raise questions about the common wisdom over the value of additional flexibility in outsourcing.

The paper contributes to the growing literature on outsourcing under environmental uncertainty (e.g., Alvarez and Stenbacka, 2007; Kogut and Kulatilaka, 1994; Kouvelis et al., 2001; Lu and Van Mieghem, 2009; Van Mieghem, 1999; Van Mieghem, 2003), by focusing on the impact of demand uncertainty and sourcing flexibility on the decision to outsource service processes and its likelihood of this decision to occur. To begin with, it presents a simple, and yet unique, analytical framework for investigating practical questions related to backsourcing flexibility. Earlier studies typically focus on the value generated from the flexibility associated with the option to outsource. We complement earlier literature by providing an analytical investigation of the likelihood of exercising the option to outsource, and by examining how including a nested option to backsource impacts the likelihood of exercising the option to outsource in the first place.

The remainder of the paper is organized as follows. Section 2 reviews the related literature. Section 3 presents the base models for full outsourcing in Regime 1 and Regime 2, along with numeric simulation results. Section 4 expands the base models to consider the impact of added sourcing flexibility in the form of partial outsourcing and the option to backsource, along with numeric simulation results. Section 5 concludes with a summary and suggestions for future research. All derivations are located in the Appendix.

2. Related literature

Our work uses a real options analysis to capture operational flexibility to outsource and backsource a business process under demand uncertainty. From a modeling perspective, Birge (2000) and Dixit and Pindyk (1994) provide good examples of how option pricing can incorporate financial risk attitudes into operational decision-making. Similar to our outsourcing and backsourcing flexibilities, Dixit (1989a,b), for example, demonstrate how these models can be used to determine whether a firm should enter and exit a foreign market.

Alvarez and Stenbacka (2007) provide the closest match to our modeling approach, although their emphasis is on the case of partial outsourcing. They investigate the effect of increasing demand volatility on the expected time of a switch to outsourcing and on the fraction of volume to outsource. Their model features the case where the outsourced cost per transaction is lower than the insourced cost per transaction, however, ignores an important component present in our model: fixed overhead costs. In Alvarez and Stenbacka (2007), the cost to switch to outsourcing depends upon the fraction of volume that is outsourced. In particular, switching cost is increasing convex in the outsource fraction, thus exhibiting diseconomies of scale. If switching cost is linear in the fraction of volume outsourced, then the model of Alvarez and Stenbacka (2007) can be viewed as a special case of our model with zero fixed costs under Regime 2. In another paper by Shy and Stenbacka (2005), split production is again justified through monitoring costs of outsourced production activities, but once again, missing the fixed overhead costs. Under the presence of monitoring costs, the firm is less likely to increase its allocation to the outsource alternative with marginal returns in order to avoid the increasing monitoring costs.

Our work is also related with the literature on outsourcing in the presence of various forms of economic uncertainty. Kogut and Kulatilaka (1994) is the first study to describe the flexibility to shift production between two manufacturing facilities with fluctuating exchange rates as equivalent to owning an option. They define market prices and the associated demand as deterministic, but variables costs are influenced by exchange rate fluctuations. When fixed switching costs are incorporated, they find that the optimal policy structure features a hysteresis band where the firm does not shift production under smaller variations in exchange rates. In a two plant scenario, Dasu and Li (1997) extend this analysis using linear and step-function switching costs in a model where exchange rate uncertainty is described with a discrete-time Markov chain. They find that regardless of whether the variable costs are concave, piece-wise linear, or convex, the optimal policy structure features a barrier policy confirming the earlier description of a hysteresis band. Kouvelis et al. (2001) study the influence of exchange rate uncertainty in the type of the ownership in production facilities in international markets (e.g., exporting, joint ventures, and wholly-owned subsidiaries). In their model, the fixed costs of switching increase as the firm's ownership in the foreign subsidiary increases, i.e., the cost is higher for switches from exporting to wholly-owned subsidiary than to joint venture. They conclude that increasing switching costs extend the hysteresis band. Other studies that emphasize capacity and/or production decisions under exchange-rate and/or demand uncertainty in a multi-period setting includes Lowe et al. (2002), Kazaz et al. (2005), Ding et al. (2007), Li et al. (2009), Pendharkar (2010), and Li and Wang (2010). Our paper differs from this stream of research in several ways. While the papers in the outsourcing stream of research consider exclusively variable costs and ignore fixed costs, our model incorporates economies of scale with the presence of fixed and variable costs. Second, the amount of service demand is random and exogenous in our model as we focus on the influence of demand uncertainty on the expected time to switch to outsourcing and the probability of making this switch. Earlier research, however, considers the amount of production/capacity volume as a decision variable.

Our study also differs from the literature that investigates the subcontracting decisions from the perspective of a low variable cost outsourcing alternative in service operations (e.g., Cachon and Harker, 2002; Osei-Bryson and Ngwenyama, 2006; Akşin et al., 2007, 2008; Ren and Zhou, 2008; Hasija et al., 2008; Milner and Olsen, 2008; Akan et al., 2011) Rather than focusing on contracting decisions as in this stream of literature, our work emphasizes outsourcing and backsourcing decisions over time. Moreover, with the inclusion of fixed costs, the outsource facility is not always the less-costly alternative. While this stream of literature utilizes queuing systems in its modeling approach, we employ a real options analysis.

3. Base outsourcing case

This section addresses the base case where it is impractical to bring a process back in-house once it is outsourced; the impact of backsourcing flexibility is examined in Section 4. Section 3.1 formalizes the problem settings and two sourcing regimes having different operating cost structures. Sections 3.2 and 3.3 proceed to illustrate each regime and develop a respective base case model for that regime. Section 3.4 compares and contrasts the two regimes through a series of numerical experiments.

3.1. Settings and two regimes

A firm is currently insourcing a transaction-based business process and has the option to outsource the process at any time in the future. The process, if outsourced, must be completely outsourced (i.e., no partial outsourcing).

We outline the notation and the modeling elements that are common to both regimes below.

Notation

F_I	fixed cost per period for operating a business process when insourced
F_O	fixed cost per period for operating a business process when outsourced
v_I	(variable) cost per process transaction when insourced
v_O	(variable) cost per process transaction when outsourced
S_{IO}	one-time fixed cost to switch an existing insourced process to outsourcing
D_0	current transaction rate
D_t	transaction rate at time t
r	firm's discount rate (net of inflation in firm and vendor operating costs)

Assumptions

(A1) The business process is currently insourced.
(A2) Transaction demand over time is modeled as geometric Brownian motion:

$$dD_t = D_t\mu\, dt + D_t\sigma\, dz,$$

where μ is the growth rate, σ is the volatility, and $z(t)$ is a standard Weiner process with $z(0) = 0$.
(A3) $r > \mu$.

Assumption A2 is common in the literature and implies that the change in transaction volume over time conforms to a lognormal distribution. Assumption A3 is the standard absence of speculative bubbles condition.

When the process is insourced, the cost rate is

$$c_I(D_t) = v_I D_t + F_I,$$

when the process is outsourced, the cost rate is

$$c_O(D_t) = v_O D_t + F_O,$$

and the expected total discounted cost of insourcing over an infinite horizon is

$$C_I(D_0) = E\left[\int_0^\infty e^{-rt}(v_I D_t + F_I)dt\right].$$

As mentioned earlier, the question of if and when to outsource arises only when no sourcing mode offers an absolute cost advantage, as in the quadrants labeled *Regime 1* and *Regime 2* in Fig. 1. We proceed to illustrate and develop the base model for each of these regimes.

3.2. Regime 1 – outsource at higher variable cost and lower fixed cost

Under Regime 1, outsourcing has a fixed-cost advantage over insourcing. The outsourced fixed cost (per period) is lower than the insourced fixed cost, but the outsourced variable cost (per transaction) is higher than the insourced variable cost. Sample services that fit this quadrant are high-skill services such as telemedicine and software development. These services involve low productivity processes and high-salaried, high-skilled labor. In insourcing, these characteristics translate into high fixed costs per period and low (or zero) variable costs per transaction.

Teleradiology, a subset of telemedicine, is a good example of Regime 1. Teleradiology is a process characterized by volume fluctuations, whether due to a barrage of incoming cases or a seasonal lull (Whitacre et al., 2007; Wachter, 2006; Singh and Wachter, 2008). Outsourcing allows healthcare providers to align radiogram reading costs to actual volumes by shifting high fixed overhead cost per period (e.g., annual salary of $250–300K per radiologist plus accreditation costs) into variable costs (e.g., $50–75 per radiogram reading). Outsourcing vendors that focus only on providing radiology reading services spread their overheads across a much larger volume of cases while optimizing and streamlining the process of physician recruiting and credentialing, radiology reading workflows, and all ancillary activities. Here, outsourcing could be favorable when the demand volume drops to a sufficiently low level.

Hence, under Regime 1 we have the following additional assumption.

(A4) $v_I \leqslant v_O$ and $F_I > F_O$.

Due to A4, $c_O(D_t) \leqslant c_I(D_t)$ if and only if $D_t \leqslant \frac{F_I - F_O}{v_O - v_I}$, i.e., low demand rates favor outsourcing and high demand rates favor insourcing. Suppose the firm elects to switch to outsourcing of the service process if and when the demand rate for the service hits a threshold rate $D < D_0$. Such a switching policy is optimal due to the stationary behavior of dz. Let $\tau_1(D)$ denote the random time of the switch to outsourcing, i.e.,

$$\tau_1(D) = \min\{t | D_t \leqslant D\}.$$

The firm's expected discounted operating cost of the process under Regime 1 is

$$C_1(D_0, D) = E\left[\int_0^{\tau_1(D)} e^{-rt}(v_I D_t + F_I)dt + \int_{\tau_1(D)}^\infty e^{-rt}(v_O D_t + F_O)dt + e^{-r\tau_1(D)} S_{IO}\right] = C_I(D_0) - V_1(D), \quad (1)$$

where

$$V_1(D) = \left(\frac{D}{D_0}\right)^\gamma \left[\left(\frac{F_I - F_O - rS_{IO}}{r}\right) - \left(\frac{v_O - v_I}{r - \mu}\right) D\right] \quad (2)$$

$$\gamma = \frac{\sqrt{(\mu - 0.5\sigma^2)^2 + 2\sigma^2 r} + (\mu - 0.5\sigma^2)}{\sigma^2}.$$

The function $V_1(D)$ is the value of the option to outsource the process given that the firm switches to outsourcing when the current demand rate passes below (or hits) threshold D. If $F_I - F_O - rS_{IO} \leqslant 0$, then it is apparent from (2) that the firm will never outsource the process (i.e., if $F_I - F_O - rS_{IO} \leqslant 0$, then $V_1(D) \leqslant 0$ for all $D > 0$). Thus, for the remainder of this section we limit consideration to cases where $F_I - F_O - rS_{IO} > 0$. The optimal threshold rate D is

$$D^* = \arg\max_{D \geqslant 0} V_1(D) = \frac{\gamma(r - \mu)(F_I - F_O - rS_{IO})}{r(\gamma + 1)(v_O - v_I)}. \quad (3)$$

The value of the option to outsource the process is obtained by substituting (3) into (2) while accounting for the fact that it is optimal for the firm to immediately switch to outsourcing if $D_0 \leqslant D^*$:

$$V_1^* = \begin{cases} \left(\frac{F_I - F_O - rS_{IO}}{r}\right) - \left(\frac{v_O - v_I}{r-\mu}\right)D_0 & \text{if } D_0 \leqslant D^*, \\ \left(\frac{\gamma(r-\mu)}{D_0(v_O - v_I)}\right)^{\gamma}\left(\frac{F_I - F_O - rS_{IO}}{r(\gamma+1)}\right)^{\gamma+1} & \text{if } D_0 \geqslant D^*. \end{cases} \quad (4)$$

We let τ_1^* denote the optimal random time that the firm switches to outsourcing (i.e., $\tau_1^* = \tau_1(D^*)$). The probability of a switch to outsourcing is

$$P[\tau_1^* < \infty] = \begin{cases} \left(\frac{D^*}{D_0}\right)^{\frac{2\mu}{\sigma^2}-1} & \text{if } \mu - 0.5\sigma^2 \geqslant 0 \text{ and } D_0 \geqslant D^*, \\ 1 & \text{if } \mu - 0.5\sigma^2 \leqslant 0 \text{ or } D_0 \leqslant D^*, \end{cases} \quad (5)$$

and the expected time to making the switch is

$$E[\tau_1^*] = \begin{cases} \infty & \text{if } \mu - 0.5\sigma^2 \geqslant 0 \text{ and } D_0 \geqslant D^*, \\ \left(\frac{1}{\mu - 0.5\sigma^2}\right)\ln\left(\frac{D^*}{D_0}\right) & \text{if } \mu - 0.5\sigma^2 \leqslant 0 \text{ and } D_0 \geqslant D^*, \\ 0 & \text{if } D_0 \leqslant D^*. \end{cases} \quad (6)$$

We note that the expected time to making a switch to outsourcing is finite when the probability of the switch is 100%, and is infinite otherwise. Thus, both measures are needed to provide a complete picture of the effect of changing parameter values on outsourcing, as illustrated in Section 3.4.

3.3. Regime 2 – outsource at lower variable cost and higher fixed cost

Under Regime 2, outsourcing has a variable-cost advantage over insourcing. The outsourced variable cost is lower than the insourced variable cost, but the outsourced fixed cost (per period) is higher than the insourced fixed cost. Sample services that fit this quadrant include call centers, claims processing, and data entry. These services involve low-salaried and low-skill labor that includes hourly and temporary workers. In insourcing, these characteristics translate into relatively low fixed costs per period. When outsourcing, there is a marginal advantage on variable costs, but this can be exploited only at the expense of increased per period monitoring and training costs for the management and quality control of outsourced work (Shy and Stenbacka, 2005; Fritsch et al., 2007).

Examples can be widely seen in data entry and call centers. Data entry covers the capture, scanning and indexing for later retrieval of standard documents (e.g., tax returns, medical claims) and unstructured documents (e.g., invoices, explanations of benefits, shipping records) (Gingrande, 2005). The variable cost per transaction is normally lower in outsourcing. For example, *Fidesic*, an e-payment services company, reports a \$0.31 variable cost for data entry of a typical non-scannable invoice, compared with \$2.42 in-house (Gingrande, 2005). This cost differential is due to the fact that the vendor uses low-cost labor, makes a high investment in technologies for automated recognition of machine print, hand print, check boxes, and barcodes. However, outsourcing usually also increases the fixed costs per period. In particular, compared to insourcing, process governance requires building and maintaining administrative process controls for supervisors to track and audit every document from the moment it is scanned until it is released to the repository, keeping tabs on who has access, when and what was done. Such tight and costly process governance is crucial for assuring high data accuracy and supporting the Health Information Privacy and Accessibility Act (HIPAA) and Sarbanes–Oxley government regulations on the handling of data.[4] This situation is also typical of call centers (neoIT, 2004). Outsourcing yields major savings on labor, but labor costs are only over 30% of the total cost of operations. In parallel, outsourcing increases the fixed costs per period mostly for communication systems, training, and process governance.[5]

These components account for 25% of the total cost of operations. The balance is in favor of outsourcing when the demand volume is large enough. Hence, under Regime 2 we have the following assumption in place of A4.

(A5) $v_I > v_O$ and $F_I \leqslant F_O$.

Due to A5, $c_O(D_t) \leqslant c_I(D_t)$ if and only if $D_t \geqslant \frac{F_O - F_I}{v_I - v_O}$, i.e., high demand rates favor outsourcing and low demand rates favor insourcing. In the event of $F_I = F_O$, we have $c_O(D_t) < c_I(D_t)$, and the decision to switch to outsourcing involves a trade-off between the outsourcing variable cost savings and the switching cost.

Suppose the firm elects to switch to outsourcing if and when the demand rate hits a threshold rate $D > D_0$. Such a switching policy is optimal due to the stationary behavior of dz. Let $\tau_2(D)$ denote the random time of the switch to outsourcing, i.e.,

$$\tau_2(D) = \min\{t | D_t \geqslant D\}.$$

The firm's expected discounted operating cost of the process under Regime 2 is

$$C_2(D_0, D) = E\left[\int_0^{\tau_2(D)} e^{-rt}(v_I D_t + F_I)dt + \int_{\tau_2(D)}^{\infty} e^{-rt}(v_O D_t + F_O)dt + e^{-r\tau_2(D)}S_{IO}\right] = C_I(D_0) - V_2(D), \quad (7)$$

where

$$V_2(D) = \left(\frac{D_0}{D}\right)^{\beta}\left[\left(\frac{v_I - v_O}{r-\mu}\right)D - \left(\frac{F_O - F_I + rS_{IO}}{r}\right)\right], \quad (8)$$

$$\beta = \frac{\sqrt{(\mu - 0.5\sigma^2)^2 + 2\sigma^2 r} - (\mu - 0.5\sigma^2)}{\sigma^2}.$$

[4] SOX's strong focus on data security and who can access what information makes outsourcing and offshoring decisions a board-level issue, particularly with invoice and remittance processing, and other organizational financial data. For example, in 2002, the frequency of non-compliance incidents, due to offshore vendor carelessness, caused the Office of the Comptroller of the Currency to issue risk-management compliance guidelines for US banks that use offshore service providers (Gingrande, 2005).

[5] These fixed costs grow in call center outsourcing for several reasons (neoIT, 2004; Holman et al., 2007):

- Communication systems require leased circuits with enough dedicated bandwidth to carry simultaneous voice and data traffic over long distances without latency, and redundancy of the links to ensure business continuity and avoid outages. IBM and Microsoft, which have outsourced their call centers to developing countries, have actually invested in dedicated telecommunications lines instead of using the Internet to field international customer calls, in order to alleviate security risks and data privacy concerns of many consumers who hesitate to give personal information over the phone (Rao, 2004).
- Training costs increase due to the need to keep in-house highly qualified personnel to develop, maintain and coordinate with the vendor a process for ongoing training and development of resources that cover both operational business needs and cultural aspects that affect service delivery. This need is aggravated by the fact that, compared to in-house call centers, vendors typically offer less training to new employees (14 vs. 20 days), employ more part-time (20% vs. 15%) and temporary workers (15% vs. 10%), have lower workforce tenure (e.g., in India, 60% of call center workers have less than one year of tenure at work), and experience higher turnover (40% vs. 19%).
- Higher process governance costs are associated with having in-house enough qualified personnel for two purposes. One is remedial work on failed calls, call backs, follow-ups, etc. A more important purpose is monitoring vendor performance. In in-house call centers, monitoring is less frequent as proximity allows supervisors to do side-by-side monitoring, wander among stations and listen in, or sit at monitoring stations. By contrast, in outsourcing, remote monitoring is harder and must be more frequent and thorough. It involves examination of call recordings and some on site visits, by specialist supervisors and "location expert resources" who are highly trained in monitoring and coaching techniques. Moreover, since pricing is often tied to service level agreements, more rigorous and frequent monitoring by the qualified specialists is needed to ensure that customer calls are being handled as promised by the vendor, on time and in a professional and quality manner.

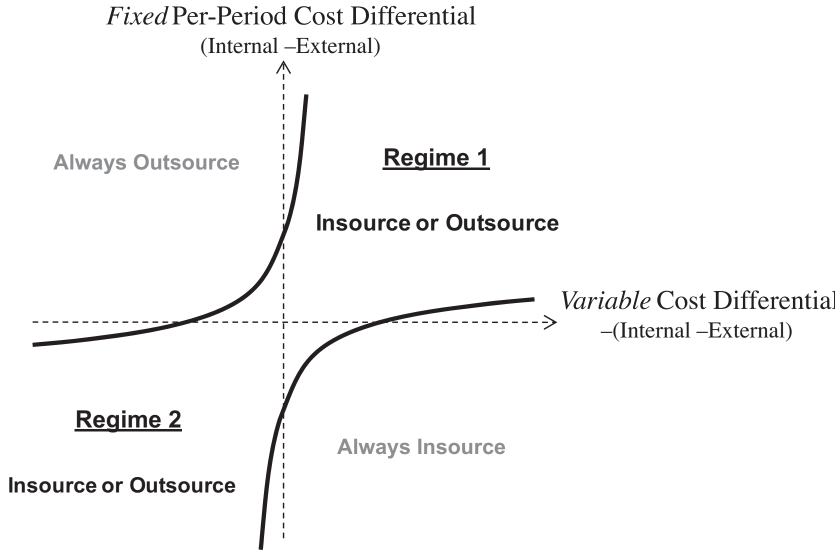


Fig. 1. Outsourcing regimes.

The function $V_2(D)$ is the value of the option to outsource the process given that the firm switches to outsourcing when the current demand rate passes above (or hits) threshold D. The optimal threshold D is

$$D^{**} = \arg\max_{D \geqslant 0} V_2(D) = \begin{cases} \frac{\beta(r-\mu)(F_O - F_I + rS_{IO})}{r(\beta-1)(v_I - v_O)} & \text{if } \beta > 1, \\ \infty & \text{if } \beta \leqslant 1. \end{cases} \tag{9}$$

If $\beta \leqslant 1$, then it is apparent from (9) that the firm will never outsource the process. Thus, for the remainder of this section we limit consideration to cases where $\beta > 1$.

The value of the option to outsource the process is obtained by substituting (9) into (8) while accounting for the fact that it is optimal for the firm to immediately switch to outsourcing if $D_0 \geqslant D^{**}$:

$$V_2^* = \begin{cases} \left(\frac{D_0(v_I - v_O)}{\beta(r-\mu)}\right)^{\beta} \left(\frac{r(\beta-1)}{F_O - F_I + rS_{IO}}\right)^{\beta-1} & \text{if } D_0 \leqslant D^{**}, \\ \left(\frac{v_I - v_O}{r-\mu}\right) D_0 - \left(\frac{F_O - F_I + rS_{IO}}{r}\right) & \text{if } D_0 \geqslant D^{**}. \end{cases} \tag{10}$$

We let τ_2^* denote the optimal random time that the firm switches to outsourcing (i.e., $\tau_2^* = \tau_2(D^{**})$). The probability of a switch to outsourcing is

$$P[\tau_2^* < \infty] = \begin{cases} \left(\frac{D^{**}}{D_0}\right)^{\frac{2\mu}{\sigma^2} - 1} & \text{if } \mu - 0.5\sigma^2 \leqslant 0 \text{ and } D_0 \leqslant D^{**}, \\ 1 & \text{if } \mu - 0.5\sigma^2 \geqslant 0 \text{ or } D_0 \geqslant D^{**}, \end{cases} \tag{11}$$

and the expected time to making the switch is

$$E[\tau_2^*] = \begin{cases} \infty & \text{if } \mu - 0.5\sigma^2 \leqslant 0 \text{ and } D_0 \leqslant D^{**}, \\ \left(\frac{1}{\mu - 0.5\sigma^2}\right) \ln\left(\frac{D^{**}}{D_0}\right) & \text{if } \mu - 0.5\sigma^2 \geqslant 0 \text{ and } D_0 \leqslant D^{**}, \\ 0 & \text{if } D_0 \geqslant D^{**}. \end{cases} \tag{12}$$

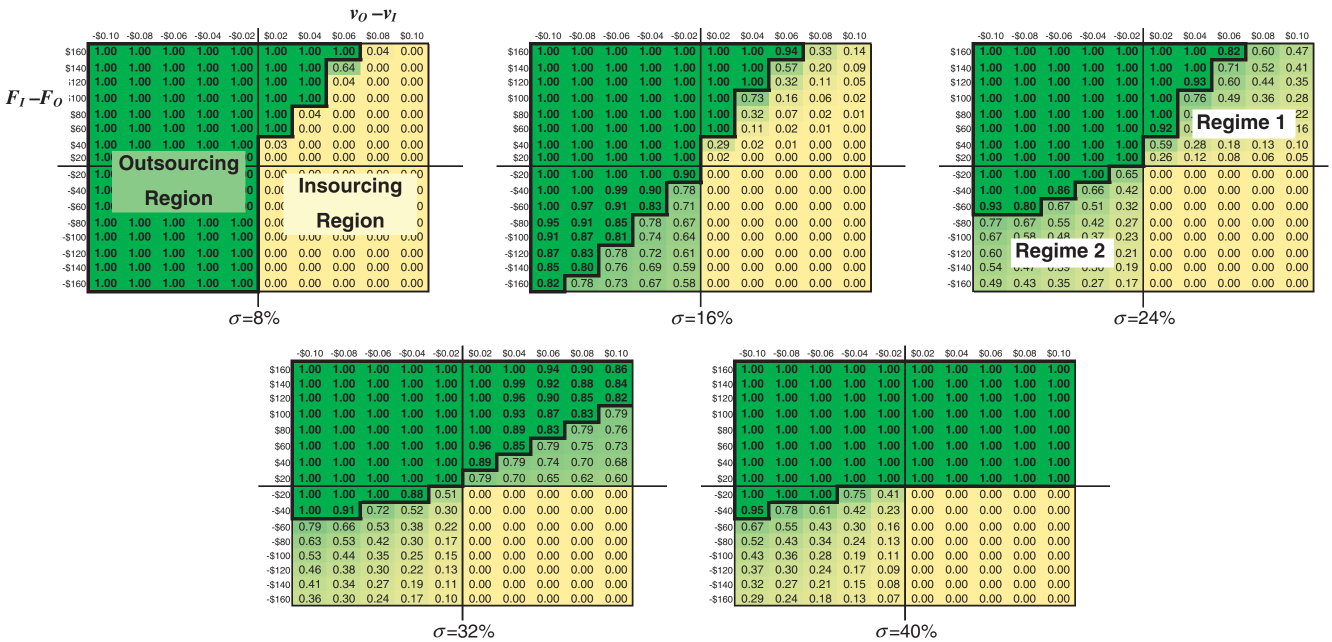
Again, we note that the expected time to making a switch to outsourcing the process is finite when the probability of outsourcing is 100%, and is infinite otherwise. Thus, both measures are needed to provide a complete picture of the effect of changing parameters values on outsourcing, as illustrated next.

3.4. Numerical analysis

We next report on how changing environmental conditions affect the likelihood of outsourcing under both regimes. Fig. 2 characterizes, within the space of possible fixed and variable cost differentials, the regions where the probability of making a switch to outsourcing is high, as a function of changing demand volatility. Assuming that a threshold probability of 0.8 is sufficiently high to trigger a decision to outsource (and the search for a vendor, terms negotiation, and contracting), we observe the following: *as demand volatility grows, the outsourcing region for Regime 1 grows and the region for Regime 2 shrinks*. This pattern is robust to changes in the values of all problem parameters.

To understand the results shown in Fig. 2, we summarize the effect of changing parameter values on the value of the option to outsource, the optimal demand threshold, the probability of a switch to outsourcing (i.e., of hitting the optimal demand threshold), and the expected time to making the switch to outsourcing (see Appendix B for details). The base models yield results similar to those of past studies in the real options literature (e.g., Dixit and Pindyk, 1994), but also refine these results and offer new insights. Principally, the value of the option to outsource increases in demand volatility, and the hysteresis band is increasing in demand volatility. The optimal demand threshold for a switch to outsourcing decreases in Regime 1 (D^*) and increases in Regime 2 (D^{**}) as a function of demand volatility, under all conditions. Generally, these conditions would suggest that a firm is less likely to outsource as volatility increases. However, the new insights our model offers refine these prediction. The probability of a switch to outsourcing and the expected time to making the switch are non-monotone in demand volatility in Regime 1 and monotone in Regime 2. Specifically, in Regime 1, the probability of a switch can be 100% mostly for relatively large levels of demand volatility (i.e., the firm immediately switches to outsourcing). By contrast, in Regime 2, for low levels of demand volatility, the probability of a switch can be 100% under most situational conditions, but this probability starts decreasing and continues to decrease as demand volatility increases.

In sum, in Regime 1, significant demand volatility increases the probability of outsourcing despite the fact it also decreases the demand threshold, and, in Regime 2, significant demand volatility lowers the probability of outsourcing as it also increases the demand threshold. Thus, in Regime 2, higher demand volatility values imply that insourcing is a better alternative for the firm. These conclusions are consistent with the expected time to making a switch to outsourcing, which decreases with increasing demand volatility in Regime 1 and increases in Regime 2. It is important to



Assumed parameter values:

$D_0 = 900$; $r = 10\%$; $\mu = 6\%$ in Regime 1, $\mu = 2\%$ in Regime 2; $v_O - v_I = \pm$ \$0.02 … \$0.1; $F_I - F_O = \pm$ \$20 … \$160; S_{IO}=\$15

Fig. 2. Outsourcing regions for the base case ($p > 0.8$).

note that all these results are robust over a range of values of problem parameters (see Appendix B).

The policy structure for Regime 1 may seem suboptimal, or even counterintuitive, but it has a logical explanation that corresponds well with the realities faced in the outsourcing of teleradiology by rural hospitals, for example. If one holds a rather long-term view on outsourcing decisions, and if demand has a positive drift, as is assumed in our numerical analyses, a policy of outsourcing when the demand falls below a threshold could be suboptimal because demand is growing in expectation and the horizon is infinite. While there is a positive probability of hitting the low demand threshold for the demand process with a positive drift and a switch to outsourcing would occur with a positive probability, the total operating cost would be lower if the firm always adopts the insourcing option throughout the horizon given that the demand is growing in expectation. However, this argument makes little sense for firms which do not, or cannot, hold a long-term view on sourcing decisions. Take the case of teleradiology in rural hospitals, for instance, where demand is volatile and has a positive drift (Whitacre et al., 2007).[6] Here, long-term considerations take a backseat to an ongoing shortage of radiology specialists as well as to “business cycle” cost pressures, budgetary constraints, and competing priorities across different specialty departments. Thus, despite having positive drift in demand, rural hospitals would chose to outsource when facing an unsustainable level of fixed costs per period at times when demand for services drops to a sufficiently low level.

4. Impact of backsourcing flexibility

This section extends the base models to account for the presence of backsourcing flexibility. Section 4.1 discusses circumstances under which this form of sourcing flexibility could offer benefits. Sections 4.2 and 4.3 study the setting where the firm has the option to break the outsourcing arrangement in midstream and bring the process back in-house. Section 4.4 contains numerical analyses of outsourcing with backsourcing flexibility under the two regimes.

4.1. Beyond the base case

As mentioned before, companies are often unsatisfied with the results of outsourcing for a variety of reasons. The main reasons are cited as high indirect costs and strategic considerations.

Indirect costs in services outsourcing can come from multiple sources. One source is errors. In data entry outsourcing, for example, delivery of inaccurate data may have expensive consequences, such as paying incorrect invoices or health claims, or hindering productivity by remedial work on problems that must be located and fixed in-house (Gingrande, 2005). Another source is of indirect costs is poor service quality, which could reduce the likelihood of future customer purchases and result in reputational damage. For instance, both Dell and Lehman Brothers moved call center operations from India back to the US due to customer complaints about service quality (Ren and Zhou, 2008). Another source is the need for close monitoring of the vendor’s work, especially when it is important to ensure compliance with such government regulations as HIPAA and SOX. For instance, a major health insurance firm has backsourced data entry operations after its service bureau in India displayed the names of company clients in a demonstration on their Website, in clear violation of HIPAA rules (Gingrande, 2005).

Strategic considerations could be more significant. They pertain to loss of control over outsourced services and of the ability to innovate. Specifically, a key concern is over the loss of expert understanding of the outsourced process and of tacit knowledge that allows the firm to have breakthrough thinking in service operations (Tiwana and Keil, 2007; Amaral et al., 2006; Takeishi, 2001). NCR Corp., for instance, backsourced the manufacturing of its most sophisticated automated teller machines (ATMs) from China and India to the US, because outsourcing distanced its designers, engineers, IT experts and customers from the manufacturing process.

[6] In teleradiology, and telemedicine in general, an aging population along with new technologies that continually expand the range of diagnostic radiology have resulted in a steadily increasing demand for diagnostic interpretations (Stack et al., 2007).

The backsourcing decision enabled the firm to turn out new models with new features fast enough to satisfy its client banks (Holstein, 2010). Similarly, GE announced that it is in the process of increasing its backsourcing capability due to strategic costs associated with the firm's technical capabilities (Layne and Green, 2011).

Firms use mainly two means to counter these concerns and reserve the flexibility to backsource in case the concerns materialize. One is to leave a group of highly qualified personnel to handle problem transactions, callbacks for incomplete transactions and follow-ups, and to benchmark the vendor's performance more accurately (Ellram et al., 2008; Whitacre et al., 2007). Another is to retain the management of the process in-house. The latter involves keeping a large internal management group to develop a proactive monitoring and management control process for interfacing with the vendor on service performance evaluation issues and, more importantly, for ensuring ongoing learning for continued process improvement and innovation (Ellram et al., 2008; neoIT, 2004; Layne and Green, 2011). Oftentimes, unless partially retained, these capabilities would be lost over the outsourced service process, and the cost to switch back to insourcing would become prohibitively large.

We next seek to examine the impact of having the flexibility to backsource on the initial decision to outsource. Consider a firm that is currently insourcing a business process and has the option to outsource at any time in the future. In addition, once the firm decides to outsource, it has the option to backsource at any time in the future. The cost to exercise this flexibility is denoted S_{OI}. The value of S_{OI} can be interpreted as the cost of breaking the outsourcing contract and switching back to insourcing. The implicit assumption is that S_{OI} is prohibitively large when the firm fails to reserve the flexibility to backsource.

4.2. Outsourcing with backsourcing flexibility under Regime 1

Under Regime 1, we have $v_I \leqslant v_O$ and $F_I > F_O$, and thus low demand rates favor outsourcing and high demand rates favor insourcing (see A4). Suppose the firm elects to switch to outsourcing if and when the demand rate hits a threshold rate $D < D_0$. As in Section 3.2, we let $\tau_1(D)$ denote the random time of the switch to outsourcing, i.e.,

$$\tau_1(D) = \min\{t | D_t \leqslant D\}.$$

At the moment of the switch to outsourcing, the firm has the option to switch back to insourcing at any time in the future. The optimal threshold for switching back to insourcing once a firm has switched to outsourcing is

$$D^{++} = \begin{cases} \frac{\beta(r-\mu)(F_I-F_O+rS_{OI})}{r(\beta-1)(v_O-v_I)} & \text{if } \beta > 1, \\ \infty & \text{if } \beta \leqslant 1, \end{cases} \tag{13}$$

where

$$\beta = \frac{\sqrt{(\mu - 0.5\sigma^2)^2 + 2\sigma^2 r} - (\mu - 0.5\sigma^2)}{\sigma^2}.$$

Note that $\beta > 1$ for any finite σ^2 (due to A3).

The value of the option to backsource at the moment the firm switches to outsourcing (i.e., the moment in time when the demand rate hits threshold D) is

$$V_2^*(D) = \begin{cases} \left(\frac{D(v_O-v_I)}{\beta(r-\mu)}\right)^{\beta}\left(\frac{r(\beta-1)}{F_I-F_O+rS_{OI}}\right)^{\beta-1} & \text{if } D \leqslant D^{++}, \\ \left(\frac{v_O-v_I}{r-\mu}\right)D - \left(\frac{F_I-F_O+rS_{OI}}{r}\right) & \text{if } D \geqslant D^{++}. \end{cases} \tag{14}$$

The firm's expected discounted operating cost is the same as in Section 3.1 except that the cost to switch from insourcing to outsourcing (S_{IO}) is reduced by the value of the backsourcing option $\left(V_2^*(D)\right)$ that is activated at the moment the firm switches to outsourcing, i.e.,

$$C_1(D_0, D) = E\left[\int_0^{\tau_1(D)} e^{-rt}(v_I D_t + F_I)dt + \int_{\tau_1(D)}^{\infty} e^{-rt}(v_O D_t + F_O)dt + e^{-r\tau_1(D)}\left(S_{IO} - V_2^*(D)\right)\right] = C_I(D_0) - V_3(D),$$

where

$$V_3(D) = \left(\frac{D}{D_0}\right)^{\gamma}\left[\left(\frac{F_I - F_O - r\left(S_{IO} - V_2^*(D)\right)}{r}\right) - \left(\frac{v_O - v_I}{r-\mu}\right)D\right],$$

$$\gamma = \frac{\sqrt{(\mu - 0.5\sigma^2)^2 + 2\sigma^2 r} + (\mu - 0.5\sigma^2)}{\sigma^2}.$$

The optimal threshold for making a switch to outsourcing is

$$D^o = \underset{D \geqslant 0, D \leqslant D_0, D < D^{++}}{\arg\max} V_3(D), \tag{15}$$

where, due to the constraints,

$$V_2^*(D) = \left(\frac{D(v_O - v_I)}{\beta(r-\mu)}\right)^{\beta}\left(\frac{r(\beta-1)}{F_I - F_O + rS_{OI}}\right)^{\beta-1}$$

there is no closed form expression for D^o (i.e., D^o is the root of a high-order polynomial). But, D^o can be obtained numerically using readily available software such as Nonlinear Solver in Microsoft Excel.

The probability that the firm will switch to outsourcing and the expected time to making the switch can be obtained from expressions (5) and (6). Given that the firm switches to outsourcing, the probability that the firm will switch back to insourcing (i.e., backsource) and the expected time to making the switch to insourcing can be obtained from expressions (11) and (12), where D^{++} is used in place of D^{**} and D^o is used in place of D_0.

4.3. Outsourcing with backsourcing flexibility under Regime 2

Under Regime 2, we have $v_I > v_O$ and $F_I \leqslant F_O$ (see A5), and thus high demand rates favor outsourcing and low demand rates favor insourcing. Suppose the firm elects to switch to outsourcing if and when the demand rate hits a threshold rate $D > D_0$. As in Section 3.3, we let $\tau_2(D)$ denote the random time of the switch to outsourcing, i.e.,

$$\tau_2(D) = \min\{t | D_t \geqslant D\}.$$

At the moment of the switch to outsourcing, the firm has the option to switch back to insourcing at any time in the future.

A firm that has switched to outsourcing will never choose to backsource if $F_O - F_I - rS_{OI} \leqslant 0$ (see (2)). Thus, for the remainder of this section we limit consideration to cases where $F_I - F_O - rS_{IO} > 0$. The optimal threshold for switching back insourcing once a firm has switched to outsourcing is

$$D^+ = \frac{\gamma(r-\mu)(F_O - F_I - rS_{OI})}{r(\gamma+1)(v_I - v_O)}, \tag{16}$$

where

$$\gamma = \frac{\sqrt{(\mu - 0.5\sigma^2)^2 + 2\sigma^2 r} + (\mu - 0.5\sigma^2)}{\sigma^2}.$$

The value of the option to backsource at the moment the firm switches to outsourcing (i.e., the moment in time when the demand rate hits threshold D) is

$$V_1^*(D) = \begin{cases} \left(\frac{F_O - F_I - rS_{OI}}{r}\right) - \left(\frac{v_I - v_O}{r-\mu}\right)D & \text{if } D \leqslant D^+, \\ \left(\frac{\gamma(r-\mu)}{D(v_I - v_O)}\right)^{\gamma} \left(\frac{F_O - F_I - rS_{OI}}{r(\gamma+1)}\right)^{\gamma+1} & \text{if } D \geqslant D^+. \end{cases} \quad (17)$$

The firm's expected discounted operating cost is the same as in Section 3.2 except that the cost to switch from insourcing to outsourcing (S_{IO}) is reduced by the value of the backsourcing option $(V_1^*(D))$ that is activated at the moment the firm switches to outsourcing, i.e.,

$$C_2(D_0, D) = E\left[\int_0^{\tau_2(D)} e^{-rt}(v_I D_t + F_I)dt + \int_{\tau_2(D)}^{\infty} e^{-rt}(v_O D_t + F_O)dt + e^{-r\tau_2(D)}(S_{IO} - V_1^*(D))\right] = C_I(D_0) - V_4(D),$$

where

$$V_4(D) = \left(\frac{D_0}{D}\right)^{\beta}\left[\left(\frac{v_I - v_O}{r-\mu}\right)D - \left(\frac{F_O - F_I + r(S_{IO} - V_1^*(D))}{r}\right)\right],$$

$$\beta = \frac{\sqrt{(\mu - 0.5\sigma^2)^2 + 2\sigma^2 r} - (\mu - 0.5\sigma^2)}{\sigma^2}.$$

The optimal threshold is

$$D^{oo} = \underset{D \geqslant D_0, D > D^+}{\arg\max}\ V_4(D), \quad (18)$$

where, due to the constraints,

$$V_1^*(D) = \left(\frac{\gamma(r-\mu)}{D(v_I - v_O)}\right)^{\gamma}\left(\frac{F_O - F_I - rS_{OI}}{r(\gamma+1)}\right)^{\gamma+1}$$

there is no closed form expression for D^{oo} (i.e., D^{oo} is the root of a high-order polynomial). However, D^{oo} can be obtained numerically using readily available software such as Nonlinear Solver in MS-Excel.

The probability that the firm will switch to outsourcing and the expected time to making the switch can be obtained from expressions (11) and (12). Given that the firm switches to outsourcing, the probability that the firm will switch back to insourcing (i.e., backsource) and the expected time to making the switch to insourcing can be obtained from expressions (5) and (6) in Section 3.2, D^+ is used in place of D^* and D^{oo} is used in place of D_0.

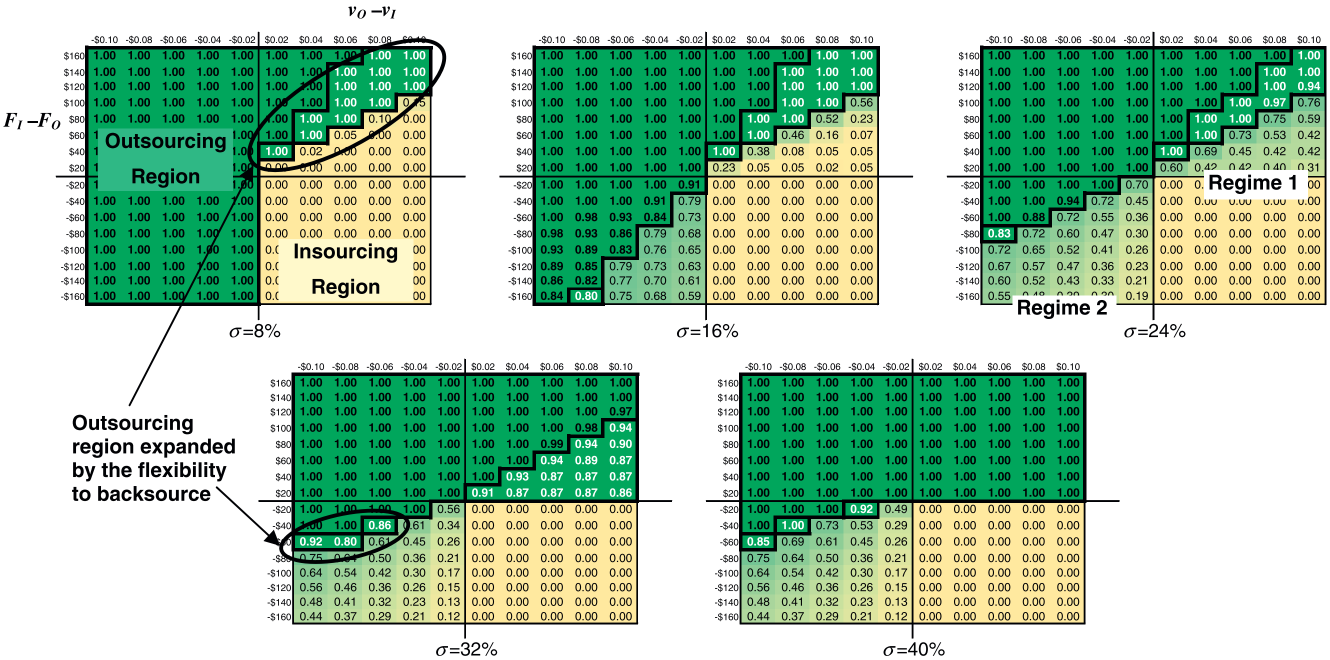
4.4. Numerical analysis

We next illustrate the influence of the option to backsource for various problem parameters under both regimes. Fig. 3 characterizes the changes in the regions where the probability of making a switch to outsourcing is high, as a function of changing demand volatility. Assuming that a threshold probability of 0.8 is sufficiently high to trigger a decision to outsource (and the search for a vendor, terms negotiation, and contracting), we observe the following: *as demand volatility grows, the presence of backsourcing flexibility expands the outsourcing region, but mostly for Regime 1*; the parts of the region showing probabilities in White font are due to backsourcing flexibility. Specifically, backsourcing flexibility expands the oursourcing region for Regime 1 rather notably under low- and medium-level demand volatilities, and only marginally for Regime 2 under all levels of demand volatility. This pattern is robust to changes in the values of all problem parameters.

To understand the results shown in Fig. 3, we summarize the effect of changing parameter values on the value contribution of the option to backsource, the optimal switching demand threshold, the probability of a switch to outsourcing, and the expected time to making the switch to outsourcing (see Appendix C for details). Starting with the *net added value* of having the flexibility to backsource, in both regimes this net added value is significant only when the value of the "plain" option to outsource (with no backsourcing flexibility) is high (see Appendix C, Figs. C1 and C2). A low value of the plain option means a negligible probability that a switch to outsourcing will occur, in which case there is a negligible value to having the flexibility to backsource. However, what is more important is how this net added value would impact the initial decision to switch to outsourcing in the first place. In *Regime 2*, while this net added value is strictly increasing in demand volatility, and the optimal demand threshold is generally lowered by the presence of backsourcing flexibility, the probability of a switch to outsourcing grows only marginally for intermediate and high values of the demand volatility, and no beneficial impact can be observed for the expected time to making a switch to outsourcing. By contrast, in *Regime 1*, the net added value of backsourcing flexibility has a significant beneficial effect on the initial decision to outsource. While the optimal demand threshold is consistently higher than that of the plain option to outsource (Fig. 2), it continues to decrease monotonically under all problem parameters until a point where the decrease tapers off significantly with increasing values of the demand volatility. As a result, the probability of a switch to outsourcing increases under all problem parameters, and the expected time to making the switch goes to zero when the probability is close enough to 100%.

In summary, introducing backsourcing flexibility into the option to outsource adds value in both regimes, but its contribution is significantly more beneficial under Regime 1. A firm operating under the cost structure of Regime 2 will have less to gain from the inclusion of the backsourcing flexibility. This is due to the long-term positive growth under both regimes, whereby expected demand is increasing in time. Thus, in the case of a service process operating in growth markets, the flexibility to reduce cost under Regime 2 by bringing transaction processing back in-house adds relatively little value. By contrast, under Regime 1, in the long term (i.e., under high service demand volumes), the firm is better off processing transactions in-house. As such, backsourcing flexibility prevents the firm from having to wait to make a switch to outsourcing until demand levels drop significantly to a point where the possibility of keeping the process in house may no longer be viable.

It is worth expanding a bit on the *net added value* of the flexibility to backsource in Regime 1. Under Regime 1, this value generally increases in demand volatility but in fact has a reversed bowl-shape for some problem parameters (see Appendix C, Fig. C1). It increases for relatively low values of the demand volatility, but decreases or just converges to a relatively stable value for higher demand volatilities. This reversed-bowl shape can be explained using properties of the model. As demand volatility increases, the stochastic demand process described by the geometric Brownian motion can hit the absorbent state (zero) with a higher probability. As the probability of experiencing zero demand increases, implying that the service process is no longer viable, the option to backsource, which is attractive when volume is high, becomes less valuable, and its net value contribution starts decreasing with increasing volatility. In essence, as volatility increases, the risks associated with service obsolescence can dominate the value of bringing a process back in-house when volume is high. This reading of the situation corresponds well with the outsourcing of teleradiology services in rural hospitals described in Section 3.1 (Whitacre et al., 2007). Outsourcing when demand levels drop sufficiently low (even if only for a temporary duration that is sufficiently long) exposes rural hospitals to the risk of having to shut down their radiology specialties and transfer all patients to larger regional hospitals, because no effective economies of scale would be sufficient to allow for any on-site radiology specialists (Whitacre et al., 2007). When this is a viable possibility, the net added value of backsourcing flexibility diminishes.



Assumed parameter values:

$D_0 = 900$; $r = 10\%$; $\mu = 6\%$ in Regime 1, $\mu = 2\%$ in Regime 2; $v_O – v_I = \pm\$0.02 \ldots \$0.1$; $F_I – F_O = \pm\$20 \ldots \$160$; $S_{IO}=\$15$

Fig. 3. Outsourcing regions for the case with backsourcing ($p > 0.8$).

Importantly, the last two results for Regime 1 refine the findings of earlier literature providing examples of how increasing market volatility creates a higher value for various forms of flexibility (Alvarez and Stenbacka, 2007; Van Mieghem, 1999; Van Mieghem, 2003; Van Mieghem and Rudi, 2002). Consistent with the findings in the real options literature, the common perception is that the value of flexibility increases with higher volatility. Yet, our results show that the incremental value of additional flexibility, in our case it is the ability to backsource an outsourced process, departs from this common understanding.

5. Summary and Conclusions

We define and analyze models for sourcing a transaction-based services process under two opposing cost structures. The cost structures correspond to the two regimes wherein the decision of whether to outsource is nontrivial. Under Regime 1 the outsourced variable cost is higher than the insourced variable cost and the outsourced fixed cost is lower than the insourced fixed cost. Examples include high-skill processes such as telemedicine and software development. Under Regime 2 the outsourced variable cost is lower than the insourced variable cost and the outsourced fixed cost is higher than (or the same as) the insourced fixed cost. Examples are low-skill processes such as data entry and call center operations.

The results of our study lead to three main conclusions that apply in settings where volume over the long-term is expected to be flat or growing. The results suggest that a careful consideration should be given to the decision to outsource service processes, especially in light of potentially high indirect costs and strategic considerations. First, the impact of demand volatility on the likelihood and timing of a switch to outsourcing depends critically on the regime. Under Regime 1, as demand volatility increases, the probability of a switch to outsourcing generally increases and the expected time to making the switch generally decreases. Under Regime 2 we find the opposite behavior; as demand volatility increases the probability of a switch to outsourcing generally decreases and the expected time to making the switch generally increases. Thus, as economic conditions become more volatile, our models predict greater levels of outsourcing of service processes having the cost structure of Regime 1, and lower levels of outsourcing of service processes having the cost structure of Regime 2. We find that these predictions continue to hold when the firm has the flexibility to backsource an outsourced process.

This conclusion refines and adds new insights into an earlier result on the relationship between volatility and the hysteresis band in a different setting. Kogut and Kulatilaka (1994) and Kouvelis et al. (2001), for example, examine the impact of exchange rate volatility on ownership structures and find that the hysteresis band is increasing in exchange rate volatility. In these studies, the increasing hysteresis band is associated with increasing persistence of the current sourcing strategy, or in other words, increasing organizational inertia. We, too, find that the hysteresis band is increasing in volatility under both regimes; the optimal demand threshold triggering a switch to outsourcing decreases in demand volatility under Regime 1 and increases in demand volatility under Regime 2. However, what we also find that is new is that under Regime 1 the probability of hitting the optimal threshold defining the hysteresis band is increasing in volatility, indicating that organizational inertial is actually decreasing in demand volatility. The result suggests that it is important for managers to account for the nature of the cost structure when considering how the attractiveness of outsourcing changes under scenarios of future high or low volatility.

A second conclusion is that the value of backsourcing flexibility is more significant under Regime 1 than Regime 2. In this light, the inclusion of backsourcing flexibility should be a higher priority for service processes with the cost structure of Regime 1. This holds particularly true in high growth markets, where the flexibility to reduce cost under Regime 2 by bringing back the service process in-house adds relatively little value.

The last conclusion is that there is a relationship between volatility and the value of flexibility which differs from conventional wisdom and earlier results. Earlier research points out that the higher the demand volatility the higher the value of flexibility (Alvarez and Stenbacka, 2007; Lu and Van Mieghem, 2009; Van Mieghem, 1999; Van Mieghem, 2003; Van Mieghem and Rudi, 2002). We show that the incremental value from incorporating additional flexibility that allows backsourcing an outsourced process can be decreasing with higher demand volatility. This result occurs under Regime 1 where higher demand volatility increases the likelihood of a switch to outsourcing and, at the same time, increases the probability that the outsourced process will not remain "viable" in-house if demand drops to a sufficiently low level. This increasing probability of service obsolescence mitigates the benefit of backsourcing flexibility, even to the point where the net value added from the backsourcing flexibility begins to decrease. A manager must be careful not to assume that increasing volatility necessarily increases the attractiveness of investments to increase flexibility.

With all this said, our models are stylized representations of reality that rely on a key assumption that may limit the applicability of our conclusions. The assumption relates to the infinite time horizon and the fact that the problem parameters are stable over the time horizon. Under a short problem horizon or non-stable parameters over time, the conclusions may change. Investigating the influence of changes in both these assumptions and an empirical evaluation of our predictions are worthy topics for future research.

Moreover, our models do not consider the outsourcing vendor's perspective. Based on our results, the pattern of client firm outsourcing behavior can clearly lower the vendor's prospect of getting the client's business, the profit it can generate even if the client decides to outsource, and the benefit from bearing the costs of making contract flexibility options available to the client. It is worth examining what strategies could help the vendor modulate the client's outsourcing behavior. Would charging a lower subscription fees per service unit outsourced induce the client to outsource earlier and increase the vendor's profit? Would both the vendor and client benefit more from the flexibility to switch to flat-fee pricing or to tiered-pricing, for example, instead of the flexibility to backsource? Examining such questions could suggest strategies that the vendor could use to induce clients to outsource earlier and stay outsourcing longer, while at the same time increasing the vendor and client benefits.

Appendix. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ejor.2011.12.007.

References

Aggarwal, N., Nair, V., Rao, A.J., 2007. Business Process Outsourcing for Property and Casualty Insurance: An Opportunity for US Insurers. White Paper, Diamond Management and Technology Consultants.

Akan, M., Ata, B., Lariviere, M., 2011. Asymmetric information and economies of scale in service contracting. Manufacturing & Service Operations Management 13 (1), 58–72.

Akşin, Z., Armony, M., Mehrotra, V., 2007. The modern call center: A multi-disciplinary perspective on operations management research. Production and Operations Management 16 (6), 665–688.

Akşin, Z., de Vericourt, F., Karaesmen, F., 2008. Call center outsourcing contract analysis and choice. Management Science 54 (2), 354–368.

Alvarez, L.H., Stenbacka, R., 2007. Partial outsourcing: A real options perspective. International Journal of Industrial Organization 25, 91–102.

Amaral, J.C., Billington, A., Tsay, A., 2006. Safeguarding the promise of production outsourcing. Interfaces 36 (3), 220–233.

Barthelemy, J., 2001. The hidden costs of it outsourcing. Sloan Management Review 42 (3), 60–69.

Birge, J., 2000. Option methods for incorporating risk into linear capacity planning models. Manufacturing & Service Operations Management 2 (1), 19–31.

Bloch, M., Spang, S., 2003. Reaping the benefits of business-process outsourcing, McKinsey on IT. Fall, pp. 1–9.

Brown, R.H. 2004. User Survey: SMB Business Process Outsourcing. Gartner Group Report G00124462. <http://www.gartner.com/DisplayDocument?ref=g_search&id=456235>.

Cachon, G.P.P.T., Harker, P.T., 2002. Competition and outsourcing with scale economies. Management Science 48 (8), 1314–1333.

Dasu, S., Li, L., 1997. Optimal operating policies in the presence of exchange rate variability. Management Science 43 (5), 705–722.

Dixit, A.K., 1989a. Entry and exit decisions under uncertainty. Journal of Political Economics 97 (3), 620–638.

Dixit, A.K., 1989b. Hysteresis, import penetration and exchange rate pass through. Quarterly Journal of Economics 104, 205–228.

Dixit, A.K., Pindyk, R.S., 1994. Investment under Uncertainty. Princeton University Press, Princeton, NJ.

Ding, Q.L., Dong, L., Kouvelis, P., 2007. On the integration of production and financial hedging decisions in global markets. Operations Research 55 (3), 470–489.

Ellram, L.M., Tate, W., Billington, C., 2008. Offshore outsourcing of professional services: A supply management perspective. Journal of Operations Management 26 (2), 148–163.

Fitzgerald, G., Willcocks, L., 1994. Contracts and partnerships in the outsourcing of IT. In: Proceedings of the 31st Annual Hawaii International Conference on System Sciences, pp. 91–98.

Fritsch, M., Wahrenburg, M., Hackethal, A., Wuellenweber, K., 2007. The Impact of Business Process Outsourcing on Firm Performance and the Influence of Governance: A Long Term Study in the German Banking Industry. Working Paper. <http://ssrn.com/abstract=1076422>.

Gingrande A., 2005. Outsourcing Data Entry: An Overview. An IMERGE Consulting Report. <http://www.datacap.com/whitepapers/documents/outsource.pdf>.

Gray, J.V., Tomlin, B., Roth, A.V., 2009. Outsourcing to a powerful contract manufacturer: The effect of learning-by-doing. Production and Operations Management 18 (5), 487–505.

Hasija, S., Pinker, E., Shumsky, R.A., 2008. Call center outsourcing contracts under information asymmetry. Management Science 54 (4), 793–807.

Holman, D., Batt, R., Holtgrewe, U., 2007. The Global Call Center Report: International Perspectives on Management and Employment Report of the Global Call Center Network. <http://www.ilr.cornell.edu/globalcallcenter/upload/GCC-Intl-Rept-US-Version.pdf>.

Holstein, W.J., 2010.The Case for Backshoring: Which Manufacturing Operations Should Return to the United States? Strategy + Business. <http://www.ffjournal.net/common/printthis.asp?currentpage=9272>.

Hutzschenreuter, T., Lewin, A.Y., Ressler, W., 2011. The growth of white-collar offshoring: Germany and the US from 1980 to 2006. European Management Journal 29 (4), 245–259.

Kazaz, B., Dada, M., Moskowitz, H., 2005. Global production planning under exchange-rate uncertainty. Management Science 51 (7), 1101–1119.

Kogut, B.N., Kulatilaka, N., 1994. Operating flexibility, global manufacturing, and the option value of a multinational network. Management Science 40 (1), 123–139.

Kouvelis, P., Axarlioglu, K., Sinha, V., 2001. Exchange rates and the choice of ownership structure of production facilities. Management Science 47 (16), 1063–1080.

Lacity, M.C., Willcocks, L.P., 2000. Relationships in IT outsourcing: A stakeholder perspective. In: Zmud, R.W. (Ed.), Framing the Domains of IT Management Research: Projecting the Future through the Past. Pinnaflex Education Resources, Inc., Ann Arbor, Michigan, pp. 355–384.

Layne, R., Green, J., 2011. Immelt Adds Technology Jobs in US as Outsourcing is Shaved. Bloomberg News on August 8. <http://www.bloomberg.com/news/2011-08-08/immelt-adds-technology-jobs-in-u-s-as-ge-shaves-outsourc ing.html>.

Li, S., Murat, A., Huang, W., 2009. Selection of contract suppliers under price and demand uncertainty in a dynamic market. European Journal of Operational Research 198 (3), 830–847.

Li, S., Wang, L., 2010. Outsourcing and capacity planning in uncertain global environment. European Journal of Operational Research 207 (3), 131–141.

Lowe, T.J., Wendell, R.E., Hu, G., 2002. Screening location strategies to reduce exchange rate risk. European Journal of Operational Research 136 (3), 573–590.

Lu, X.L., Van Mieghem, J.A., 2009. Multimarket facility network design with offshoring applications. Manufacturing & Service Operations Management 11 (1), 90–108.

Mani, D., Barua, A., Whinston, A.B., 2005. Of Process Analysis and Alignment: A Model of Governance in BPO Relationships. University of Texas at Austin, Working Paper.

Milner, J., Olsen, T., 2008. Service-level agreements in call centers: Perils and prescriptions. Management Science 54 (2), 238–252.

Miriyala, K., Gurbaxani, V., 2005. Transaction-based Pricing Model for Outsourcing: Why and When. White paper, iGATE Global Solutions, Bangalore, India, April.

neoIT, 2004. Total Cost of Offshore (TCO): Understanding the True Offshore Financial Rewards and Costs, Offshore Insights. White Paper Series, May. <http://itonews.eu/files/f1213794631.pdf>.

Osei-Bryson, K.M., Ngwenyama, O.K., 2006. Managing risks in information systems outsourcing: An approach to analyzing outsourcing risks and structuring incentive contracts. European Journal of Operational Research 174 (1), 245–264.

Pendharkar, P.C., 2010. Valuing interdependent multi-stage IT investments: A real options approach. European Journal of Operational Research 201 (3), 847–859.

Rao, M.T., 2004. Key issues for global IT sourcing: Country and individual factors. Information Systems Management 21 (3), 16–21.

Ren, J.Y., Zhou, Y., 2008. Call center outsourcing: Coordinating staffing level and service quality. Management Science 54 (2), 369–383.

Samuels, M., 2005. The insourcing trend is bringing it all back home. IT Week, May 12. <www.computing.co.uk/computing/features/2072478/insourcing-trend-bringing-back-home>.

SAP, 2006. The Impact of Technology on Cost in BPO: The Complete Business Process Outsourcing Cost Picture. SAP White Paper.

Shy, O., Stenbacka, R., 2005. Partial outsourcing, monitoring cost, and market structure. Canadian Journal of Economics 38 (4), 1173–1190.

Singh, S., Wachter, R., 2008. Perspectives on medical outsourcing and telemedicine: Rough edges in a flat world? New England Journal of Medicine 358 (15), 1622–1627.

Spohrer, J., Maglio, P.P., 2008. The emergence of service science: Toward systematic service innovations to accelerate co-creation of value. Production and Operations Management 17 (3), 238–246.

Stack, M., Gartland, M., Keane, T., 2007. The offshoring of radiology: Myths and realities. SAM Advanced Management Journal 72 (1), 44–51.

Takeishi, A., 2001. Bridging inter- and intra-firm boundaries: management of supplier development in automobile product development. Strategic Management Journal 22 (5), 403–433.

Tan, C., Sia, S.K., 2007. Managing flexibility in outsourcing. Journal of the Association for Information Systems 7 (4), 179–206.

Tiwana, A., Keil, M., 2007. Does peripheral knowledge complement control? An empirical test in technology outsourcing alliances. Strategic Management Journal 28 (6), 623–634.

Van Mieghem, J.A., 1999. Coordinating investment, production, and subcontracting. Management Science 45 (13), 954–964.

Van Mieghem, J.A., Rudi, N., 2002. Newsvendor networks: Inventory management and capacity investment with discretionary activities. Manufacturing & Service Operations Management 4 (4), 313–335.

Van Mieghem, J.A., 2003. Capacity management, investment, and hedging: Review and recent developments. Manufacturing & Service Operations Management 5 (4), 269–302.

Veltri, N.F., Saunders, C.S., Kavan, B., 2008. Information systems backsourcing: Correcting problems and responding to opportunities. California Management Review 51 (1), 50–76.

Wachter, R., 2006. The ‘dislocation’ of US medicine: The implications of medical outsourcing. New England Journal of Medicine 354 (7), 661–665.

Weakland, T., 2006. 2006 Global IT Outsourcing Study. White Paper, Diamond Cluster International, Spring.

Wentworth, D., 2008. TrendWatcher: Backsourcing—Bringing HR Processes Back In-house. <http://www.hrworld.com/features/trendwatcher-backsourcing-072508/>.

Whitacre, B.E., Hartman, P.S., Boggs, S.W., 2007. The Economic Impact of Telemedicine Capability in a Rural Hospital. National Center for Rural Health Works, Oklahoma State University, Oklahoma Cooperative Extension Service. <www.ruralhealthworks.org>.

Whitten, W., Leidner, D., 2006. Bringing IT back: An analysis of the decision to backsource or switch vendors. Decision Sciences 37 (4), 605–621.