Measuring the Return on Information Technology: A Knowledge-Based Approach for Revenue Allocation at the Process and Firm Level[*]

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Abstract

This paper proposes an approach for measuring the return on Information Technology (IT) investments. A review of existing methods suggests the difficulty in adequately measuring the returns of IT at various levels of analysis (e.g., firm or process level). To address this issue, this study aims to develop a method for allocating the revenue and cost of IT initiatives at any level of analysis using a common unit of measurement.

Following the knowledge-based view (KBV), this paper proposes an analytic method for measuring the historical revenue and cost of IT investments by estimating the amount of knowledge necessary to generate a common unit of output from any business process. The

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[*] Sirkka Jarvenpaa was the accepting senior editor.

amount of required knowledge is operationalized using the 'average learning time' measure. The proposed operationalization is illustrated with a practical case example.

The proposed KBV approach is extended specifically for IT resources, allowing us to assess the Return on IT (ROIT) using a typical productivity ratio (similar to ROI or ROA) that accurately captures the true business value of IT (despite any complementarities) at virtually any level of analysis.

Keywords*:* Return on IT, Business Value of IT, IT Productivity, Knowledge Value-Added, IT Theory, Knowledge-Based View, IT Investments, Thermodynamics, Learning Time

Introduction

There have been numerous approaches to assessing the performance impact of IT investments, both at the firm and the process levels (see Kohli and Devaraj, 2003 for a review). At the firm level, the key question is how IT initiatives affect firm performance (Brynjolfsson and Hitt, 1993; Brynjolfsson and Yang, 1996; Dos Santos, Peffers and Mauer, 1993; Im, Dow and Grover, 2001; Richardson and Zmud, 2002; Subramani and Walden, 2001). At the process level, the question is about the impact of IT investments on specific processes (e.g., Barua, Kriebel and Mukhopadhyay, 1995; El Sawy 2001; Ray, Muhanna and Barney, 2005). In general, the literature has shown that IT may often facilitate firm performance, yet not conclusively. Besides measurement concerns, lag effects, poor IT investments, and inappropriate IT implementation and use, the infamous "IT productivity paradox" may be due to the fact that the output of IT initiatives is perhaps better observed at the process level (versus the firm level) (Barua et al., 1995; Kohli and Devaraj, 2003; Ray et al., 2005). In other words, IT-driven firm impacts may not readily materialize because of various firm-level, industry-level, or other contingencies (Melville, Kraemer and Gurbaxani, 2004). To address the inconclusiveness regarding the returns on IT investments, this study proposes that a *common measurement unit* is needed to describe the output of business processes and allocate the firm's revenue and cost, regardless of the chosen level of analysis (process or firm level).

To justify enormous IT investments, there should be some relationship between the impact of IT investments and both specific firm processes and overall firm performance. However, many other variables that affect firm performance (e.g., firm size, industry structure, new technologies, and government regulations) make it difficult to infer that a specific IT investment has resulted in a specific change in a firm process or overall firm performance (Bharadwaj, 2000). Another difficulty is that IT inputs are often intertwined with complementary factors (Barua et al., 1995; Brynjolfsson and Yang, 1996; Brynjolfsson and Hitt, 1998). Provided that the cost and the revenue due to IT (plus other complementary factors) could be specified at a given point in time, it would be possible to establish an independent return ratio for productive assets, including IT. Given that this approach has not yet been proposed in the literature, this study aims to introduce an analytic method for measuring the performance impacts of IT resources by ex-post allocation of historical *revenue* and *cost* to IT investments, regardless of potential complementarities with intertwined factors.[1]

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[1] Given that IT resources are often intertwined with other factors, the theory of complementarities (e.g., Barua et al. 1995) suggests that it is difficult to perfectly distinguish between IT and

The proposed approach assumes that it is possible to describe the outputs of all firm processes in common units by employing a *knowledge metaphor.* The basic assumption is that processes are surrogates for their respective outputs, and that by using a common language based on process knowledge estimates, it is possible to describe the outputs of processes in common units. Following the knowledge-based view (Kogut and Zander, 1996; Nahapiet and Ghoshal, 1998; Nonaka, 1994; Zander and Kogut, 1995), the assumption is that knowledge is required to produce outputs of a process, and it is possible to describe the output in common units. The proposed conceptualization is based on the relationship between the knowledge required to produce a given firm output (whether that knowledge is contained in human or IT resources), and the time it would take the "average" learner to acquire that knowledge to produce the output. The longer it takes the common reference point (the average learner) to learn how to produce a given output, the more complex is the knowledge required. In this fashion, the operational definition of knowledge is defined in terms of *learning time*. Since learning time is verifiable through various objective means, the resulting estimates can be checked for their reliability. The proposed operationalization – *average learning time* – (corrected for biases using normal sampling and ensuring reliability of estimates) can thus be measured in common units of time. Learning time is proposed as a surrogate for common units of output, and it can be used for allocating the firm's revenue and cost to the common units of output.[2]

In practice, to achieve an accurate estimate of the knowledge embedded in IT investments using the same descriptive language of learning time, it is also possible to observe the outputs of IT and estimate how long it would take the average learner to acquire the required knowledge to produce the desired output. For example, in the case study reviewed in this paper (Section 4), SBC Telecom documented how to produce the outputs of the various IT investments in the event of IT failure. This provides a convenient way to assess how long the average learner would take to learn how to produce the outputs of IT.

By being able to describe process outputs in common measurement units based on their knowledge complexity, it then becomes possible to first allocate the firm's *revenue* to the common units of output produced by the knowledge embedded in productive assets (e.g., employees or IT assets) of each process. In other words, the proposed approach allocates the price paid for these common units of output (i.e., the historical revenue) across the firm's various processes. Second, given that outputs are described in common measurement units, it is also possible to get estimates for the *cost* per unit of output. In the knowledge metaphor, the time it takes to master the knowledge to produce a common unit of output is a convenient way to estimate cost. More specifically, the execution time multiplied by the cost of the productive assets (i.e., employees and IT assets) provides a way to estimate cost using common units of output.

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complementary factors (due to non-linearities). To address this issue, this method allocates revenue and cost to the joint factor (that captures all complementarities), and it then distributes the cost and revenue among its constituents.

[2] It is assumed that when customers pay a certain price for a firm's output (e.g., a product), they pay for the all the outputs of the firm at that point in time. For example, when you purchase an automobile, you pay a price that is distributed across all processes (e.g., product development, manufacturing, quality control, finance, marketing, sales, accounting) used to produce the automobile. This historical revenue and its associated cost is what the proposed method aims to allocate.

Applied to IT investments, we propose an approach for estimating the Return on IT (ROIT) investments by allocating historical revenue and cost data to a firm's outputs described in common units. Accounting for the revenue and cost of IT investments (and since revenue and cost are derived independently), it thus becomes possible to calculate a productivity measure of the firm's IT (ROIT). Generating a return-over-cost ratio specifically for IT investments would create a typical productivity ratio (similar to ROI or ROA) that would enable an accurate assessment of the value added by IT investments. It would also make it possible to use established firm-level performance information to make decisions about the performance of individual firm processes or activities. In sum, allocating revenue to IT investments allows the use of a return-based ratio, both within a firm's boundaries and across inter-firm processes.

Given the multiple benefits of such a ROIT ratio, it becomes imperative to develop a framework for ex-post allocation of revenue and costs to IT at *any* firm, functional, or process level to map the economic impact of IT initiatives. Since IT researchers and managers have recently come under a great deal of scrutiny to justify the role of IT on productivity, it is necessary for the IS community to build a common framework for understanding, evaluating, and justifying the impact of IT investments on process improvement and firm performance. For IS researchers, such a ratio would largely eliminate the need to infer the role of IT using the typical approach of controlling for all possible inputs and assuming that the residual value is due to IT. This ratio would permit estimating the returns of specific IT initiatives (e.g., customer relationship management, enterprise resource planning, e-commerce) at either the firm or process level.

Managers would benefit from the use of a performance metric that uniquely specifies the impact of IT investments, allowing them to justify, longitudinally track, and finally estimate the impact of their IT investment decisions on the performance of specific processes at any level of aggregation. From a managerial standpoint, it is important to reiterate that the proposed approach is based on historical data, which are commonly used in the finance and accounting literatures to describe firm performance over a given time. This historical analysis also is used to predict future firm performance. Consequently, we do not make any claims about *prescribing* future firm or process output, future revenues, customer value, or ROIT, other than making predictions based on historical data.

The paper's primary contribution is to introduce the possibility of, and propose a conceptual framework for, allocating revenue to IT investments and estimating a return on IT investments. Given the difficulty in developing a solid theory and a corresponding operationalization for unambiguously allocating revenue across the firm, the primary goal of this paper is to stimulate a debate and future research on measuring the returns on IT investment through the allocation of revenue to productive assets within the firm. Such debate would help establish superior theories and operationalizations for allocating revenue derived from IT investments, thereby helping managers, analysts, and investors predict and assess the value-adding role of such investments.

Section 2 reviews prominent current approaches for measuring ROIT, concluding with a set of criteria for developing a new measurement approach. Section 3 presents and describes the proposed knowledge-based view for measuring the ROIT, and Section 4 presents a case example that demonstrates the operationalization of the proposed method. Section 5 discusses the implications of the proposed approach, and Section 6 concludes by urging IS researchers to develop their own approaches for allocating revenue and enabling new forms of IT performance measurement.

Review of Measuring Returns on It Investments

Given the importance of establishing and measuring the returns on IT investments, the IS and related literatures have proposed numerous methods. This brief literature review section aims only to give a representative view of the original papers in order to develop a set of criteria for a new approach to measure ROIT. For a more comprehensive review of the literature, please see Kohli and Devaraj (2003) or Melville, Kraemer, and Gurbaxani (2004).

This literature review will demonstrate that there are four key requirements for developing a defensible approach for measuring the return on IT investments:

- A perspicuous theoretical framework
- Specific allocation of revenue and cost to IT initiative
- Mapping of the IT impact at any level of aggregation (firm and process)
- A means to describe all outputs in common units of measurement

Research on estimating the value added by IT can be categorized at two levels of analysis: (1) corporate (firm) level, and (2) sub-corporate (process) level. We summarize the focus of Section 2 in Table 1 and review the studies contained therein in sections 2.1 and 2.2.

Table 1 - Common Approaches for Measuring the Return on IT						
Level of Analysis	Approach	Focus	Example	Key Assumption	Key Advantage	Limitation
Aggregate Corporate (firm) level	Process of Elimination	Treats effect of IT on ROI as a residual after accounting for other capital investments	Knowledge capital (Strassmann 2000a, b)	ROI difficult to measure directly	Uses commonly accepted financial analysis techniques and existing accounting data	Cannot drill down to effects of specific IT initiatives
	Production Theory	Determines the effects of IT through input output analysis using regression modeling techniques	Brynjolfsson & Hitt (1996)	Economic production function links IT investment input to productivity output	Uses econometric analysis on large data sets to show contributions of IT at firm level	"Black-box" approach with no intermediate mapping of IT's contributions to outputs
	Resource-Based View	Linking firm core capabilities with competitiveness	Jarvenpaa & Leidner (1998)	Uniqueness of IT resource = competitive advantage	Strategic advantage approach to IT impacts	Causal mapping between IT investment and firm competitive

						advantage difficult to establish
Corporate/ sub-corporate	Option Pricing Model	Determines the best point at which to exercise an option to invest in IT	Benaroch & Kauffman (1999)	Timing exercise option = value	Predicting the future value of an IT investment	No surrogate for revenue at sub-corporate level
Sub-corporate (Process)	Family of Measures	Measure multiple indicators to derive unique contributions of IT at sub-corporate level	Balanced score-card (Kaplan & Norton, 1996)	Need multiple indicators to measure performance	Captures complexity of corporate performance	No common unit of analysis/ theoretical framework
	Cost-Based	Use cost to determine value of information technology	Activity-based costing Johnson & Kaplan (1987)	Derivations of cost ≈ value	Captures accurate cost of IT	No surrogate for revenue at sub-corporate level -- no ratio analysis
	Knowledge Value Added	Allocating revenue to IT in proportion to contributions to process outputs	Housel & Kanevksy (1995)	IT contributions to output ≈ IT value-added	Allocates revenue and cost of IT allowing ratio analysis of IT value-added	Does not apply directly to highly creative processes

Firm Level Approaches

Firm level approaches aim to understand the contribution of firm assets (e.g., knowledge and technology) to a firm's performance. At the firm level, the most popular techniques are: (a) process of elimination, (b) production theory, (c) resource-based view, and (d) option pricing, as described below:

The Process of Elimination Approach

In the *process of elimination* approach, once the capital costs (e.g., equipment, IT assets, real estate) are accounted for and income is proportionately is reduced, the residual is asserted to be revenue attributed to knowledge capital (Strassman, 2000a, 2000b). Baruch Lev's method (www.stern.nyu.edu/~blev) on valuing firm knowledge capital follows the process of elimination approach. This method estimates the value of knowledge capital by subtracting the expected income from a firm's tangible and financial assets from past and

expected earnings to give the firm's "knowledge earnings." Lev applies a discount rate to the average post-tax return for three knowledge-intensive industries to obtain the firm's knowledge capital. In essence, this approach identifies the value of knowledge capital by subtracting the effect of all other assets and accounting for what remains.

A similar method applies to IT: since costs attributed to all cost categories (except IT) reduce income, the remaining income is attributed to IT.[3] The limitation of the 'process of elimination' approach is that it only applies at the aggregate firm level, and thus is unlikely to allow precise inferences about IT-driven performance improvements at the process level (Birchard and Nyberg, 2001).

The Production Theory Approach

Others have used economic-based production theory to determine the various contributions of inputs to the firm's output. Hitt and Brynjolfsson (1996) asessed the value of IT in terms of *productivity*, *profitability*, and *consumer welfare*. Extending this research, Brynjolfsson and Yang (1996) broadly report the effect of IT on overall firm performance. The resulting "production function" (Brynjolfsson and Hitt, 1996, p. 545) can be modeled using economic theory to determine the unique contributions of IT. Computer and non-computer capital, IT labor, and other labor expenses are viewed as the inputs (which represent all firm spending and investments) and output in terms of monetary or physical units. This neoclassical economic theory of production treats the firm as a "black box" and attempts to deduce the relationship between inputs and outputs without reference to activities within the firm.

The strength of such approaches derives from their reliance on commonly accepted economic theories and the use of existing accounting data that makes them transparent for review and comparison. However, various criticisms have been leveled at these approaches, including that they do not "adequately control for other factors (other than IT) that drive firm profits" (Bharadwaj, 2000, p. 170). Similarly, Im et al. (2001, 104) confirm, "Because many factors influence firm performance, it is difficult to establish causality between IT investments and firm-level output performance." This lack of intermediate mapping of IT impacts on processes makes firm-level approaches problematic for providing the feedback necessary to help managers determine whether IT investments do pay off.

The Resource-Based View Approach

The *resource-based view* (RBV) attempts to overcome these shortcomings by reformulating the question and attempting to link a firm's output to firm-specific IT resources, such as IT capabilities (Bharadwaj, 2000).[4] A limitation of the RBV is that it does not posit a common,

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[3] Strassman (2000b) provides a brief review of the essence of how the knowledge capital metric is a form of economic value-added. "By filtering out the contributions of financial capital from the reported profits, we are left with a residual that is entirely attributable to what knowledge capital has actually delivered… As a reminder, one can compute the knowledge capital of a firm by taking a year's worth of economic value-added-the financial returns from assets that do not show up in financial reports." He also reports on the essence of Lev's proprietary method for calculating knowledge capital: "Lev introduces a simple ratio for determining the valuation of a firm's knowledge capital. Strassman (2000a) defines it as "...the normalized earning minus earnings from tangible and financial assets divided by knowledge capital discount rate."

[4] Resources include financial assets, IT, employees, and company brand. Capabilities are firm-specific and refer to the ability to leverage resources to produce value. Jarvenpaa and Leidner (1998, p. 343) summarized the approach: "Focusing on the firm level analysis, the resource-based view emphasizes

granular unit of analysis that would allow a specific mapping between a firm's use of IT and the resulting value-adding performance. Therefore, it would still be difficult to definitively determine the specific contribution of a given IT initiative.

The Option Pricing Approach

The application of *option pricing models* (OPM) for evaluating IT initiatives has attracted increasing attention (Benaroch and Kauffman, 1999).[5] Basically, the OPM approach determines the best point at which to exercise an option to invest. In the context of real options investments six variables are used to make the decision (Amram and Kulatilaka, 1999, p. 37): (1) the current value of the underlying asset, (2) the time to the decision date, (3) the investment cost or exercise price (also called the strike price), (4) the risk-free rate of interest, (5) the volatility of the underlying asset (which is often the only estimated output), and (6) cash payouts or non-capital gains returns to holding the underlying assets. The OPM approach has some implicit assumptions that are potentially limiting. For example, net present value is used in the risk calculation, which requires an assumption about projected cash flows. However, there is no cash flow directly attributable to most firm processes because their outputs are not salable to end customers (without the outputs of all other processes), limiting the OPM applicability at the process level.

The current aggregate (firm) level approaches do not appear capable of precisely determining the role of IT on performance at the process level so as to benefit managers who must implement IT initiatives at the sub-corporate level. Such process-level approaches are described next:

Process (Sub-Corporate) Level

At the process level, approaches to determining the impact of IT can be classified as: (a) family of measures, (b) cost-based, and (c) knowledge value-added.

The Family of Measures Approach

The *Family of Measures* (*Balanced Scorecard* and *Intellectual Capital Navigator*) approaches advocate the need to measure multiple indicators to derive unique IT contributions at the sub-firm level. The Balanced Scorecard approach uses 4-5 key performance indicators selected by management to determine the success of a given strategic firm thrust (Kaplan and Norton, 1996). The managerial team might select the IT initiative for assessment via a set of outcome indicators (customer satisfaction, financial performance, employee satisfaction, process performance). Edvinsson and Malone's (1997) Intellectual Capital Navigator allows a firm to identify up to 140 variables (e.g., laptops/employee, IT expense/employee, IT staff/staff, IT literacy of employees) that account for the performance of its intangible assets, including IT initiatives (p. 109). The limitation of the Family of Measures approaches is the lack of a common theoretical framework and unit of analysis that would convincingly link IT investments to a firm's performance (Bharadwaj, 2000), leading to an inherent subjectivity problem in terms of specifying the weight of each measure.

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the resources possessed, developed, and deployed by an organization and understanding the relationship of those internal resources with performance competitiveness." These resources and capabilities are difficult to copy, and they can thus provide a basis for a competitive advantage.

[5] The options pricing model can be used to assess returns on IT investments at both the corporate and process level.

Cost-based methods often use underlying replacement costs (e.g., transfer pricing, internal markets, outsourcing) to determine the value of IT (Housel and Bell, 2001). These approaches assume that the cost of IT is in some way proportionate to its value. For example, the cost to replace or outsource IT is presumed to be proportionate to the value it adds to process performance. Similar cost-based approaches assume that by introducing a market mechanism where firm managers submit bids for IT services, the resulting internal "market price" is representative of the true value of IT (Ba, Stallaert and Whinston, 2001).

The Activity Based Costing Approach

Activity Based Costing (ABC) is a common cost-based approach. It is useful for finding and evaluating the true costs of process activities (Johnson and Kaplan, 1987). Applications of ABC to measuring IT impacts assume that any costs saved (or processes simplified, and thus costs reduced) by the IT are a direct reflection of its value. This assumption may be true in cases where costs are reduced, and process outputs remain constant or increase.

The conceptual limitation of cost-based approaches is the lack of a surrogate for revenue (Johnson, 1992). The problem of using cost as a surrogate for value is that all information is contained in the denominator of the productivity ratio. Ideally, the information about value should come from the revenue side of the firm's performance (the numerator).

Other Practical Approaches

The current economic environment has also placed a great urgency on achieving greater precision and providing valid and reliable approaches for estimating the ROIT. For example, the practitioner CFO community has sought measures for capturing IT initiatives. Bannan (2001) argued that CFOs would like to see a ROIT measure, but since such a measure is lacking, they have to settle for less concrete and more general measures (e.g., number of hits, page views). Lenatti (2003) argued that a way to estimate the ROI on IT is necessary to secure project funding and measure project success.

Conceptual Framework

A General Approach for Describing Outputs in Equivalent Units

The purpose of firms is to produce value via their processes by transforming inputs (e.g., energy, information) into outputs (e.g., final products/services). The proposed conceptual framework for measuring ROIT is based on a method to describe the outputs of any given process in equivalent measurement units. Such methods would be able to:

- Compare all processes in terms of their relative productivity
- Allocate revenue to common measurement units of output
- Describe the value added by IT resources in terms of the outputs they produce
- Relate outputs to the cost to produce those outputs in common measurement units
- Describe a common unit of measurement for firm productivity

The Knowledge Based View

The knowledge-based view (KBV) argues that the firm's primary function (and reason for existence) is to leverage knowledge into productive outcomes (Kogut and Zander, 1996; Nahapiet and Ghoshal, 1998; Nonaka, 1994; Zander and Kogut, 1995). The KBV describes

firm resources and capabilities as knowledge sets (Leonard-Barton, 1992). Knowledge is the stock of intellectual assets accumulated through experience, learning, and ongoing practices (Sambamurthy, 2000). Capabilities (the effectiveness in executing business processes) are thus generated through an ongoing process of absorbing information, converting it into knowledge, and utilizing knowledge to effectively undertake functional activities. Knowledge broadly encompasses facts, symbols, data, discussions, workflows, tasks, whiteboard sessions, human expertise, and scientific understanding (Becerra-Fernandez and Sabherwal, 2001).

In order to fully understand what is knowledge, it is important to distinguish between knowledge and information by proposing two distinct categories: (a) information or explicit, codifiable knowledge and (b) know-how or tacit knowledge (Alavi and Leidner, 2001; Grant, 1996; Kogut and Zander, 1992; Nonaka, 1991). Information or explicit, codifiable knowledge can be easily exchanged, shared, stored, and retrieved without much loss. On the other hand, know-how or tacit knowledge is the information that has been processed in the minds of individuals through deliberation, learning, and judgment (Alavi, 2000). Despite this distinction, it is important to clarify that these two categories are not dichotomous, but they are mutually-dependent and reinforcing facets of knowledge (Polanyi, 1975). As Tsoukas (1996) suggests, tacit and explicit knowledge are inseparable. Nonaka and Takeuchi (1995) further propose that knowledge is created through interactions among different combinations of tacit and explicit knowledge. Therefore, the proposed view encompasses both tacit and explicit knowledge.[6]

A Knowledge-Based View of Business Processes

Our proposed theoretical framework is based on the amount of change each business process (P) produces, which is essentially the difference between input (A) and output (B), as shown in Figure 1.
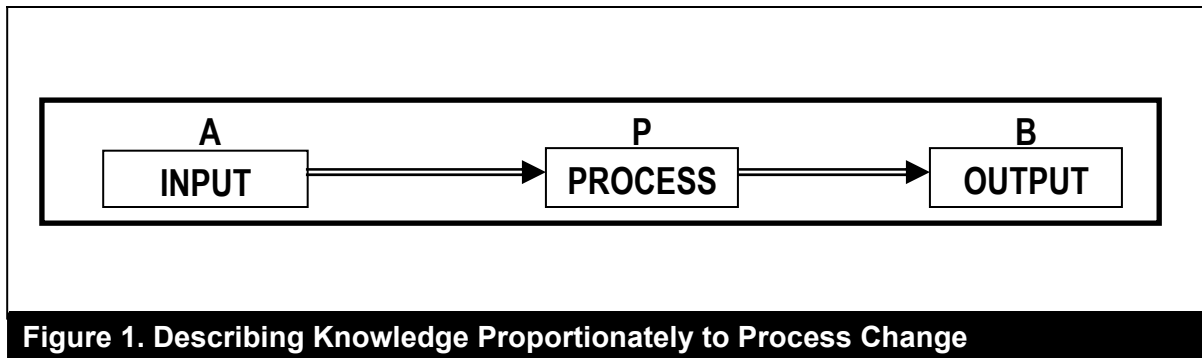

Figure 1. Describing Knowledge Proportionately to Process Change

Following KBV, we contend that the change between a certain input A and output B is based on the knowledge (tacit and explicit) needed to drive the business process (P). It follows that introducing changes to a process, through IT for example, that do not produce changes in the process output (e.g., in terms of its characteristics, cost or quality) adds no value. To illustrate, if a process is fully or partially automated via the use of IT, then the amount of change or value added by IT can be measured precisely as long as A is changed into B.

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[6] Even if the proposed approach encompasses both tacit and explicit knowledge, it is obviously easier to describe explicit knowledge and estimate the required 'learning time'.

Conversely, if the change added by a process is purely dependent on the way the process operates (and not on the output of the process), then every process change would represent a change in value, even if the actual output of the process does not change at all. Therefore, the description of a process in terms of the elementary changes it requires to produce outputs from inputs provides a common units surrogate for the output. In this way, knowledge described in terms of the changes produced by a process can become a common units surrogate for the output of the process.

a. Revenue Allocation

At a given point in time, a firm's revenue is best represented by the aggregate output of its processes. A firm's revenue is obtained simply by multiplying the price it charges for its products by the quantity sold. It is important to mention that firms price their products to maximize their revenue, and price is often independent of the cost needed to produce the products. Most important, it is beyond the scope of this study to explain or predict how revenue is received, or how well a firm's products are priced to maximize revenue. Our goal is simply to take historical revenue received and allocate it to the firm's productive processes.

Since knowledge essentially drives the transformation of inputs into outputs in any given process, following KBV, the total knowledge required to produce this aggregate output is a surrogate for the firm's total revenue. If knowledge can be described in common units, then it is possible to allocate the firm's revenue to these units of knowledge. This would allow the establishment of a common price per unit of knowledge. Thus, it follows that revenue per unit of knowledge is a surrogate for revenue per unit of common output.

Extended to IT resources, this formulation allows a direct linkage between a firm's revenue and the knowledge distributed among its IT resources (and other complementary or independent resources) needed to produce revenue. It then becomes possible to allocate the revenue produced by the knowledge in firm processes, and specifically the knowledge contained in the IT resources.

IT is often just one of many resources within a firm, and problems often arise because it often complements other firm resources in generating value (Barua and Mukhopadhyay, 2000). Complementarity represents an enhancement of resource value since synergies among firm and IT resources are likely to create greater returns (Milgrom and Roberts, 1995). Following complementarity theory, Barua et al. (1996) proposed the "calculus of reengineering" in which IT returns may be a non-linear (super-modular) function of the contributing complementary factors. Consequently, Barua, Kriebel and Mukhopadhyay (1995) developed a model of IT value in which the impact of IT on firm performance is mediated by intermediate processes.

To address potential complementarities between IT and other synergistic factors, our proposed method allocates revenue to a joint factor combining IT and complementary resources, and translates it into common units of knowledge. This formulation captures non-linear synergistic effects. Having captured the revenue produced by the joint factor, revenue can then be allocated among the constituent factors (i.e., IT resources and other synergistic resources). This allocation can be theoretically performed at any level of analysis by analyzing the details of each process and specifying the contribution of each productive factor (knowledge required to perform each factor's contribution).

A trade-off arises between the level of detail required to precisely allocate revenue and the effort required to disentangle and thoroughly describe the process to identify each unique contribution. In such cases, management needs to step in to allocate revenue based on a simple heuristic (roughly equal contribution), or to specify the level of detail in the process description that is needed to make a more accurate allocation.[7]

b. Cost Allocation

The proposed approach also provides a means to estimate the denominator (cost) of the productivity ratio, where the costs of routine process executions, execution errors, poor quality, lack of training, and poorly designed IT, for example, can be captured in terms of the cost to execute any given process. Following the proposed approach, cost is also allocated using common units of knowledge, and the aggregate cost estimates at the process level can thus be directly linked to the firm's total cost. Thus, the costs are comparable across the organization, and they can be used to compare the cost of producing process outputs across processes.

Our approach is similar to cost accounting methods because fixed costs are uniformly spread across all processes, representing a constant factor in calculating the productivity (revenue over cost) across firm processes. Labor costs, however, are usually distinct across processes, particularly IT labor, which often represents one of the highest cost drains.

Allocating costs among complementary factors is problematic as well, especially for IT resources that usually create value only in combination with other resources. Our cost allocation approach would first determine the total cost for the joint (combinatory) factor in common units, then for each of the constituent factors. The granularity and accuracy of the cost allocation decision is based on the degree of detail desired by management.

c. A Productivity (Revenue over Cost) Ratio

Summarizing the preceding discussion, since we derive revenue and cost allocation independently, our approach can establish a productivity ratio (revenue over cost). This ratio allocates a percentage of revenue to a given process based on (a) the amount of knowledge required to produce the process outputs in the numerator, over (b) the cost to employ the knowledge in the denominator.

This productivity ratio can be used at any aggregation level (process or firm) to first estimate the Returns on Knowledge (ROK) for each chosen level of analysis, and then extend this ratio to IT resources to estimate ROIT investments.

Operationalizing Knowledge with "Learning Time"

Several ways to operationalize the amount of process change have been proposed in the literature, such as information bits, process instructions, Hay knowledge points, and Jackson Structural diagrams) (see Housel and Bell (2001) for a review).

While there are numerous ways to estimate the amount of knowledge required in a process, following the KBV, *learning time* is proposed to be a simple, quick, and convenient

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[7] This procedure is not much different from any cost accounting allocation decisions. For example, when two cost units share a similar overhead, a management decision needs to be made in terms of the percentage that needs to be absorbed for each unit.

operationalization because knowledge contained in any given process is proportionate to the time it takes to learn it. Processes with predetermined outputs may be described in terms of the amount of time it takes the average learner to learn how to produce these outputs. The proposed learning time estimation method assumes that the time it takes for an "average person" to learn to execute a given process is proportional to the amount of knowledge needed (Kanevsky and Housel, 1998) and is a descriptive and practical surrogate for the corresponding amount of process change. The proposed operationalization is summarized in Table 1.

Table 2. The Operationalization of the Knowledge-Based Conceptualization
1. If A=B, no change has been added by process P
2. If A is changed by P in to B, then "value" is proportionate to the amount of "change"
3. Change can be measured by the amount of knowledge needed to make the changes
4. Knowledge is proportional to the time it takes an average learner to acquire the knowledge
5. Value and change are then proportionate to the time it takes an average learner to acquire the knowledge required to make a change

Applied to IT investments, learning time is the time an average learner needs to acquire the knowledge needed to use an IT system to drive a business process or produce the process output.

This description of the study's theoretical framework and proposed operationalization can be described in the context of management decision-making with simple examples (Table 3).

The learning time analogy can be used to establish an analytic measure of the common units of change executed by firm processes with predetermined outputs.[5] Because the learning time proxy allows for the measurement of process changes in common units, it then becomes possible to allocate revenue in proportion to the amount of learning time at any level of analysis.

Table 3. An Illustrative Example of the Proposed Operationalization
Let's assume that we teach the "average" person everything she needs to know, including how to produce all the outputs of IT investments and how to produce all outputs for any given firm. In a very real sense then, her knowledge of the firm would be the embodiment of the firm's value-added processes. Therefore, it is these core processes (e.g., selling, marketing, production, accounting, finance) that change process inputs to value-added outputs. When combined, these outputs generate the firm's revenue. We can put this understanding to the test with a simple example. In the widget company,

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[5] Some processes do not have predetermined outputs such as those that are highly creative. However, the outputs of these processes eventually find their way into those processes that are more deterministic and can therefore be accounted for within the context of processes with predetermined outputs. If they do not, then they are in "inventory" for possible later use in the processes that produce company products.

there is one person, the owner, who makes and sells widgets. This person knows all there is to know to make widgets, which sell for $1. The owner's sales-production knowledge can be used as a surrogate for the $1 of revenue generated by his application of the core process knowledge. We can ascertain how long it would take the widget company owner to transfer all the necessary sales and production knowledge to a new owner. Furthermore, we could use these learning times to allocate the $1 of revenue between the sales and production processes. In this sense, the knowledge is a surrogate for the amount of change produced by the sales and production processes.

For simplicity, let's assume that it takes 100 hours for a new owner to learn both processes, with 70 hours spent to learn how to make the widget and 30 hours to learn how to sell it. Of the 70 hours of learning time, let's assume that 20 hours were used to learn how to produce the outputs of the IT used to support the production process. This would indicate that 70% of the knowledge, elementary changes or complexity, and value added were contained in the production process and 30% in the sales process. It would follow that $.70 of the revenue was generated by the production knowledge, and $.30 by the sales knowledge.

Having determined how much it will cost to use the sales and production knowledge, we would then have a ratio of knowledge revenue to knowledge cost, or Return on Knowledge (ROK). It is a simple extrapolation from there to generate the ROIT ratio by partitioning the amount of knowledge the IT used to produce the outputs of these two processes. Then, by allocating revenue to these IT outputs and subtracting the cost to produce these IT outputs (divided by the cost to produce the IT outputs), we would have an ROIT estimate.

Let's assume that the total cost to sell and produce the widget was $.50: $.25 cost for sales and $.25 for production. Of the production cost, $.05 was the cost to use the IT supporting the production process. We would conclude that the production process provided a better utilization of the knowledge asset (ROK=.70/.25=280%) than the sales process (ROK=.30/.25=120%). Further assume that the IT in the production process accounted for 20 units of output and cost $.05 to produce. Thus the ROIT would be .20-.05/.05 or 300%.

The revenue attributable specifically to the knowledge embedded in IT and the cost to use IT would provide the ROIT within and among processes. This can be quite revealing in that "all IS are not created equal." Some highly automated processes would likely provide much lower ROIT compared to others, where there is a lower percentage of automation but where the IS provides much more "bang for buck."

Reliability and Accuracy of 'Learning Time' Operationalization

Due to concerns over the accuracy of the learning time estimates, multiple learning time methods have been used to determine the level of correlation among estimates. Such estimates can be checked against standard training times for given process tasks (Section 4). For example, subject matter experts (SME) are asked to estimate how long it would take a common reference point learner to learn how to produce the process outputs. In this case, they are also asked to assume that the supporting IT process has been removed, and that the common reference point learner must now learn how to produce the IT outputs. Where possible, these estimates are then compared to actual training times for learning how to produce specific process outputs. The assumption is that there is an average learning time across many learners. As a practical exercise, learning time estimates for common reference point learners can be grounded so that any biases will be equally distributed.

When SME have trouble estimating learning times, the process instruction method is applied, and the SME are asked to describe the instructions required to teach the common reference point learner how to produce the outputs of a process. If estimation problems still remain after these efforts, a more detailed and time-consumer analysis is performed for the problem areas. In general, normal sampling methods apply to all approaches in order to ensure a reasonable estimate of the change produced by the focal processes.

Validating 'Learning Time' Estimates

The learning time method can also be complemented by the *process instruction* or *binary query* approach to assess the reliability of the 'learning time' estimates. The learning time approach is practical and enables less costly, more rapid estimations of the amount of change produced by processes. Poorly performing processes can then be selected for more precise analysis techniques as required to support resource allocation decisions.

Finally, the proposed learning time method can be compared with other estimates of process change (e.g., process instructions) to assess the reliability of the obtained estimates. In the learning time approach, the total amount of learning time required to market, finance, sell, produce, account for, and distribute a firm's outputs (i.e., sellable products or services) is a surrogate for the revenue derived from a firm's outputs during a given sample period. The outputs of all the firm processes used to generate this revenue, at a given point in time, can be described in common units of learning time. It follows that "price per unit of output," or its surrogate "price per unit of knowledge," (which is derived by dividing firm revenue by the total number of units of knowledge) is a constant. However, the cost per unit of knowledge will vary depending on the cost to use the knowledge (e.g., human and IT resources) to produce a process output.

Case Example Of Learning Time Operationalization

To illustrate the use of the learning time operationalization for measuring the value added by IT investments, we present an example derived from a case study we conducted with SBC Telecom.[8]

This example demonstrates the use of *normalized* and *actual* learning time for estimating process changes in equivalent units of knowledge, thus allowing revenue allocation at the process level (and to the supporting IT).[9]

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[8] Special thanks to Professor Richard Chase (University of Southern California) for helping us develop this case example to help explain the essence of the proposed operationalization from a management perspective. In addition to SBC Telecom, the proposed 'learning time' operationalization has been applied in over 100 companies (both profit and not for profit) and repeatedly in a number of these companies. Management and process subject matter experts found the learning time approach to be intuitive and relatively easy to apply to derive reliable estimates. A frequent comment by the participants was that this method took significantly less time (on average 14 days for one analyst to complete an analysis of a core process), than other competing methods (e.g., activity-based costing).

[9] A number of compromises have been made for the sake of simplicity. For example, in the aggregate level example, it would have been preferable to observe the actual number of times the knowledge in each process was used to produce outputs within a given sampling period. The process level example

The data-gathering team calculated the learning times, as well as the actual number of training days required to learn all the sub-processes of the firm's core processes for the aggregate level example. The team used a single point of reference for learning time estimates (i.e., one of the team members) to ensure that biases would be evenly distributed across all estimates. In addition, the relative learning times were based on the amount of time it would take the single point of reference learner to learn all the processes if they only had a total of 100 months. The normalization to 100-months technique has been used to benchmark the telecom industry and other industry segments, including the consulting industry (Housel and Hom, 1999).

Case Example—Correlations among Learning Time Estimates

The team correlated the multiple estimates with each other as a basic estimate of their reliability. Given that the estimates are derived using a common theoretical framework, a simple correlation is a reasonable approximation of the reliability. In this case example, the relative learning time estimates were highly correlated with actual training time estimates (94%) and thus with the training time estimates being used for all subsequent calculations (Table 4).

Table 4. Simple Correlation Table for Corporate Level Example		
Column 1	Column 2	Column 3
Multiple Knowledge Estimates Reliability	Relative Learning Time (100 months)	Actual Average Training Period (Hours)
Marketing	6	500
Ordering	12	923
Provisioning	36	13,000
Maintenance	20	7,300
Billing	7	300
Customer Care	11	1,218
Administrative Support	4	1,000
Sales	4	2,448
Correlations	Column 2 & 3= 94%	

The purpose of getting two (*normalized* and *actual*) estimates of learning time was to check the reliability of the obtained estimates. In other instances where such actual learning time referents may not be available, SME can be asked to assess the actual learning time, and inter-rater reliability measures can then be taken. SME could also be asked to decompose core processes into their sub-processes and then estimate how long it would take the reference point learner to learn how to produce the outputs of each sub-process step. While greater accuracy requires a longer time commitment, for rough estimates, the normalized and actual (via estimates among several SME or actual training times) learning time estimates suffice. A correlation of .80 or higher is typically sufficient to proceed with the calculations of the ROIT estimates.

provides the number of times knowledge was used, in addition to the learning time and process instructions estimates for change in sub-processes.

Case Example—Interpretation of the Return on Knowledge (ROK) Results

The calculations of the ROK ratios are included in Tables 5 and 6. We purposefully left out the fixed costs because they were spread evenly across all processes (similar to traditional cost accounting methods). For example, the cost for power, maintenance, and real estate was spread evenly across all processes. The most significant variable cost was labor.

The *Provisioning* and *Maintenance* processes were orders of magnitude more complex than other processes and required much more time to learn as well as more support from IT. This is because these two processes represent an aggregation of many sub-processes (for example, in the case example, there are 15 legacy systems required to provision an order, and 11 systems to complete a maintenance order). These IT systems are essentially used to manipulate and keep inventory records. Much less time is required to learn how to order, support, sell, market, and bill. This is because the product was well known within a highly regulated industry where the customer had limited choice.

Table 5. ROK Estimates for Aggregate Example							
Column 1 Core Processes	Column 2 Learning Time	Column 3 IT Learning Time	Column 4 Total Learning (in hours) (Col. 2 + Col 3)	Column 5 % Total LT (Col. 4/Total LT)	Column 6 Total Annual Cost Per Process Area	Column 7 Revenue Allocation (Col. 5 * Total Revenue)	Column 8 ROK (Col. 7 / Col. 6 - 100%)
Marketing	500	150	650	1.5%	$2,700,000	$2,350,585	-13%
Ordering	923	692	1615	3.75%	2,875,000	5,841,205	103%
Provisioning	13000	7800	20800	48.24%	12,583,721	75,218,734	498%
Maintenance	7300	4380	11680	27.09%	10,016,279	42,238,212	322%
Billing	300	240	540	1.25%	4,025,000	1,952,794	-51%
Customer Care	1218	853	2071	4.8%	4,775,000	7,487,880	57%
Corporate	1000	600	1600	3.71%	6,425,000	5,786,056	-10%
Sales	2448	1714	4162	9.65%	20,000,000	15,049,533	-25%
TOTALS	26689	16429	43118	100.0%	63,400,000	155,925,000	146%

Our goal was to generate relative return performance estimates. Table 5 shows the ROK results, which provided a framework for beginning the process of prioritizing IT initiatives to support redesigned processes. The ROK performance data serve the purpose of providing a baseline from which to iterate various process redesign models. For example, the ROIT to support the sales process (Table 6) provides a baseline comparison for a process redesign using a new customer relationship management (CRM) system to support the sales process.

One method for estimating the learning time for IT is to ask a process SME to estimate how long it would take the average learner to learn how to produce the output of the IT, *if* the IT failed. Given that most processes have not always been automated with supporting IT, the

SME would estimate how long it would take to teach the referent learner how to produce the outputs that automation is now producing. In case the IT produces new outputs that were never produced manually, the SME would have to estimate how long it would take a referent learner to learn how to produce the new outputs. In either case, the SME can be asked to decompose the IT outputs into the steps required to produce the IT outputs manually, and these steps can then be calibrated in terms of learning time.

Table 6. ROK Estimates with IT Partitioned from Total Learning Time					
Column 1 Core Process	Column 2 IT LT	Column 3 % IT LT of overall Total LT (Col. 2/Total IT LT)	Column 4 IT Costs	Column 5 Revenue IT LT (Col. 3 * Total Revenue)	Column 6 ROK on IT (Col. 5/Col. 4) - 100%
Marketing	150	.91%	$600,0,00	$540,978	-10%
Ordering	692	4.21%	1,000,000	2,495,711	150%
Provisioning	7800	47.48%	3,583,720	27,130,848	685%
Maintenance	4380	26.66%	1016279	15,796,553	1454%
Billing	240	1.46%	2,900,000	865,565	-70%
Customer Care	853	5.19%	2,000,000	3,076,361	54%
Corporate	600	3.65%	800,000	2,163,911	170%
Sales	1714	10.43%	2,000,000	6,181,573	209%
TOTALS	16429	100%	13,900,000	59,251,500	326%

Interpretation of the Return on IT (ROIT) Results

Our aggregate level analysis included the amount of learning time that was attributable to the IT to support the core processes. Because firm management had developed contingency scenarios where all IT systems failed, it had purposefully developed training to manually produce the same outputs as the IT systems. We used the firm's training time estimates for the IT learning times, which permitted partitioning of the estimates for supporting IT (Table 6).

This partitioning made it clear that some forms of IT support provided better returns than others. For example, the IT system that supported the sales process provided substantially better returns than the IT system that supported the billing process, and the maintenance process resulted in the best ROIT. Even though the legacy IT systems supporting provisioning and maintenance were older file processing systems, they had been specifically created to support these highly optimized core processes. However, in the case of the highly automated legacy billing systems, the outputs of the legacy system process cost more than the actual revenue allocated to the process. This result indicated that billing was a process in need of serious attention by management, and led them to place it on a watch list for future reengineering with creation of a new billing module explicitly designed to be implemented with a sales and services CRM system.

The poor performance of the marketing IT was not a primary concern of the firm's management team because it was believed that this area would not benefit from further automation. Some areas may be more prone to benefit from IT support than others. It is also possible that the marketing IT may not have been utilized to its fullest capacity because the marketing personnel were not familiar with its advanced statistical modeling and simulation

capabilities. Because our approach only measures IT systems in use and not IT systems in inventory, it can only indicate the performance of IT in actual use. There are numerous examples of IT that has much greater functionality than is being utilized in the processes supported by the IT. A poor ROIT may indicate that the functionality of the IT is under-utilized, the legacy IT requires expensive maintenance, or the IT system is used infrequently.

This example may appear counter-intuitive because the legacy IT systems were so productive. However, the results indicate that even legacy IT systems could provide an acceptable return when deployed in processes for which they have been specifically designed and optimized for a specific purpose. It follows that pure reliance on the type of IT (e.g., file processing system - legacy systems, web-based) may not be the critical differentiator in terms of predicting IT performance. Process design may be the most crucial issue in predicting and maintaining the highest ROIT.

This case example therefore demonstrates that the cost of IT investments may not necessarily be related to the output (value) it produces. For example, the IT maintenance system provided substantially higher returns that any of the other IT systems. This result also demonstrates that it is critical to derive both the numerator and denominator of any IT investment from different sources: namely, the numerator for revenue allocation and the denominator for cost allocation.

In summary, this case example demonstrates that our approach for measuring change in processes to estimate output can be operationalized and measured in relatively practical ways. The advantage of this approach is that, while grounded in a solid theoretical framework, it can easily be applied in practice. This approach can obtain practical estimates that are grounded in common units of knowledge, and these units can be used as a surrogate for process change. Finally, the proposed approach can be readily used to obtain estimates for the specific contribution of IT.

A Simplified Approach for obtaining Learning Times Estimates

The detailed analysis outlined in the case example is relatively time consuming; however, managers can obtain rough estimates by conducting a quicker analysis, as summarized in Table 7.

Table 7.　　A Quick Analysis of the SBC Telecom Case Study
To conduct a quick analysis of the SBC Telecom company, we would gather the various managers of core processes (sales, marketing, network provisioning, maintenance, etc.). We would then ask them to estimate how long it would take the 'average' learner to learn how to produce the output of each core area with the following boundary condition: we only have a total of 100 months for our average person to learn everything necessary to generate the annual revenue at SBC Telecom. This form of normalization would lead to quick, rough cut estimates of the distribution of outputs among the various core areas, processes, and functions, which can then be used to allocate the annual revenue. We can also ask the managers to estimate the percentage at which an area is automated. This provides a way to estimate the allocation of revenue to IT. Admittedly, this is a very rough estimate, but it provides the benefit of getting the managers to agree on the basic principle that knowledge can be used to describe firm outputs.

> We would not ask the executives to make estimates of the value of their core processes, since this might degenerate into a no-win 'dog' fight. In contrast, we would ask them to achieve consensus estimates of approximately how much time our average person should use (of the total allotted 100 months), to learn each core process, including how to produce the outputs of IT investments. These estimates would be weighted by the number of employees in each core process. This is a rough cut way of estimating how often the knowledge in a given process is used annually. The percentage of knowledge for each process (including its supporting IT) would then be calculated (process knowledge/total amount of knowledge), and revenue would be allocated proportionately.
>
> If we wanted to understand the contribution of IT, the revenue for each process could be further partitioned into the amount attributable to the knowledge embedded in the supporting IT. The annual budget for each area can be used to estimate the cost to use the given core process knowledge (in most high-tech firms, as SBC Telecom, this will simply be the cost for employee salaries and IT costs). The final step would be to divide the allocated revenue by the cost per core process to determine the relative returns.

Discussion

Despite numerous approaches to assess the performance impact of IT investments, the literature has not conclusively shown that IT investments have a positive effect on either firm or process performance. To address this paradox, this study argues that a *common measurement unit* is required to allocate the revenue and cost of IT investments at any level of analysis (firm and process). Following the KBV, our proposed approach (which applies to virtually all levels of analysis) first captures the knowledge needed to drive firm processes (and thus change of inputs into outputs) and translates it into a numerical form that allows allocation of revenue in proportion to the value added by this knowledge. Second, it also assesses the actual cost of the knowledge needed to execute the given process. Given that revenue and cost are independently assessed, their resulting ratio provides a ROK ratio. This ratio readily applies to IT initiatives since IT is an integral part of the knowledge needed to drive firm processes. Therefore, a Return on Information Technology (ROIT) ratio can be derived.

In terms of the operationalization of the knowledge required to drive firm processes, we propose to employ the time it would take the average learner to acquire that knowledge needed to produce a process output. Average learning time is a simple, convenient, and reliable operationalization for capturing the complexity of the knowledge required to drive business processes.

Implications for Theory and Research

There are several implications for theory and research of employing the proposed approach for obtaining the ROK and ROIT at various levels of analysis. The following sub-sections describe how the proposed method relates, draws upon, and extends: (1) the IT assessment literature and existing methods for measuring the returns on IT (e.g., option pricing, internal markets, and RBV), and (2) the theory of complementarities.

Implications for Existing Approaches for Measuring the Return on IT

As reviewed earlier, many approaches have been proposed in the IS and related literatures to measure the ROIT. Our method could complement many of these approaches, such as the option pricing model, the internal markets model, and the RBV, as described below.

Option pricing models hold great promise for predicting future investments in IT, but they could benefit from having a surrogate for cash-flow and discounted cash-flow at the process level, such as the ones derived from our approach. The historical data captured over time using this approach would also provide the volatility ranges that can be used as inputs to option pricing models. The advantage of integrating our proposed approach with existing option pricing models is that this new source of raw data would make it possible to evaluate options based on comparable data (similar to financial options models). This would provide researchers the necessary historical data that would allow them to generate a more comprehensive application of option pricing models at the process level in terms of hedging, financial risk, and other historical trends.

Internal market models would also benefit from the ability to allocate and project revenue to various IT initiatives at the process, department, or firm level. This would allow comparisons among the various cost-based and knowledge-based frameworks for predicting how managers would negotiate with each other on the basis of projected cash-flows derived from investments in new IT systems at the process, department, or firm level.

Finally, RBV methods would benefit from tracking the effects of specific capabilities, deployed in people as well as IT. This could be achieved by identifying the capabilities that produce the greatest returns over time. For example, if resources – such as customer knowledge that supports web-based interfaces – did result in a competitive advantage, this should also be reflected through the contributions of such capabilities to a firm's performance over time.

Implications for the Theory of Complementarities

IT-enabled business processes usually include the deployment of both IT and other complementary resources, since synergies among IT and related resources are likely to render greater returns due to potential complementarities (Milgrom and Roberts, 1995). Following complementarity theory, Barua et al. (1996) argue that IT returns may have a non-linear (super-modular) function of the contributing complementary factors that is higher than the sum of the returns of individual constituent factors. Following the theory of IT complementarities, our proposed approach does not assume that the output of firm processes is a linear function of the returns to IT and other complementary factors, but rather it argues that any complex IT-related processes can be captured as long as their output can be described in terms of the knowledge required to produce the output. The more complex the complementarities between IT and other resources, the more learning time it would probably take to master the knowledge to produce such outputs. Having identified the joint contribution of a set of complementary factors, the proposed approach theoretically enables the identification of each factor's unique contribution by analyzing the complex process in greater detail. Even if it is practically superior to employ simple revenue allocation heuristics (e.g., equal contribution) without scrutinizing each factor's distinct contribution, it is theoretically feasible to specify the unique contribution of IT and other complementary factors at virtually any level of analysis and specificity.

The proposed method thus has implications for the theory of IT complementarities in the sense that it first identifies the contribution of any complementary effects, and it can then specify each factor's unique contribution by describing the underlying process at any level of disaggregation. At a minimum, this approach provides one possible method for measuring the complementary effects of IT resources as they participate in the production of complex process outputs. Most important, it can even further distinguish the unique contributions of IT resources by describing business processes at a greater level of detail.

Our approach also assumes that one of the advantages of having a firm entity is derived from the complementarities among its processes. Using this approach, process managers will quickly recognize that any benefits obtained at the expense of lowering the performance of other processes would only be temporary. This is because the overall firm performance is not likely to improve if the costs are pushed from one area to another. Therefore, if various complementary processes cooperate to provide a greater overall value, the result will be a higher revenue to allocate to all processes and a lower cost to each of them (and thus higher firm performance).

Implications for Practice

The proposed approach addresses a long-held need recognized by executives, IT managers, and investors – how to leverage and measure the knowledge embedded in IT systems, employees, and related productive assets.[10] By applying this approach specifically to IT resources, managers can benefit from a performance metric that uniquely specifies the impact of IT, allowing them to justify, track, and finally assess the impact of their IT investment decisions on the performance of specific processes, functions, or the entire firm. Moreover, by tracking the conversion of knowledge into process value, managers can increase the productivity of their business processes.

Managers who redesign business processes require a method for determining how much their process design decisions will influence existing processes, at first, and firm performance, overall (El Sawy, 2001). The proposed approach provides a simple and reliable way to estimate the returns that alternative process designs can generate.

Our method also applies to cost allocation decisions, allowing firms to allocate the costs of virtually any process using common units. In doing so, it enables managers to compare the cost of knowledge across processes, allowing them to identify unreasonably costly processes. For example, Johnson Controls used our approach to arrive at a more comparable costing methodology for two products coming off the same assembly line. One of the products was significantly more expensive, but when it was decomposed via the knowledge required to complete the production process, they Johnson Controls discovered that on a common unit of output basis it was actually much less expensive to produce.

With a common reference point to discuss the revenue and cost of a given business process, managers can focus their attention on improving both halves of the return equation (revenue and cost) and avoid a reliance on cost as the sole determinant of their decision making. This dual focus also provides better protection for investors, who ultimately want to see increasing

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[10] The proposed method is embedded in several software programs, such as the enterprise management and monitoring software suite produced by eCGSoft, Inc. (www.ecgsoft.com). This software allows ongoing monitoring of knowledge data, which is a relatively routine task for managers.

IT returns. In fact, investors would be able to accurately track the performance of IT investments over time (without having to disentangle the role of IT investments), allowing them to reward firms that make sound IT investments that improve business processes and facilitate future cash flows rather than forcing them to rely on alternative means, such as announcements regarding IT initiatives to infer future firm performance (Rodgers and Housel, 2001).

Limitations and Suggestions for Future Research

The proposed approach has a number of limitations that call for future research opportunities.

First, this approach applies primarily to processes with predetermined outputs, assuming that there is a "shortest description" of the knowledge required to change inputs into outputs. However, since there is theoretically no shortest description, this approach requires a compromise for inferring the shortest process description. Moreover, describing the knowledge required to drive complex processes is not always an easy task. Accordingly, estimating the average learning time for producing a given output is often difficult and time-consuming, especially for complex processes. Future research could simplify the necessary description of knowledge-intensive processes and find alternative operationalizations that are more appropriate for complex processes.

Second, our method may not readily apply to creative and unpredictable processes, such as R&D. Nevertheless, for the output of R&D processes to be of value to firms, it must eventually find its way into processes with predetermined outputs, such as manufacturing, production, and quality control. From this perspective, it is possible to use the approach to track the conversion of such creative outputs into value as they are embedded in processes with predetermined outputs. However, future research could attempt to extend the proposed approach to creative and unpredictable processes.

Third, the proposed method is an analytic technique that uses historical data, similar to most cost accounting approaches. Therefore, it is not explicitly designed for making prospective estimates. In fact, most methods for predicting the performance of a firm are based on extrapolations of historical data. However, predicting changes in revenue, especially in a competitive fashion, is a natural next step for future research. Future research could thus attempt to extend the proposed method to make prospective estimates.

Fourth, establishing a market price for the output of non-profit firms has been a problem for public economics for some time. One valuation approach that shows promise is the market comparables method. Following this method, it may be possible to establish a defensible theoretical basis for comparing non-profit processes with their for-profit comparable processes. Given that the output of each process can be described in common measurement units, it may be possible to assign the comparable market price per unit from the for-profit firms to the non-profit ones. Future research could clarify the theoretical soundness and practical operationalization of this possible extension.

Finally, similar to the limitations of complementarity theory, it is not easy to trace the exact contribution of each complementary factor. Consequently, since IT resources are often intertwined with other complementary factors, it may not be possible to accurately calculate the ROIT, especially for complex processes. Future research could attempt to trace the exact contribution of the underlying complementary factors.

Conclusion

Assessing the performance impact of IT investments is one of the holy grails of the IS field. In fact, IT executives have recently come under a great deal of scrutiny to show the impact of IT on firm productivity and profitability. It is thus necessary for the IS field to build a common framework for understanding, evaluating, and justifying the impact of IT investments on process improvement and firm performance. Moreover, it is incumbent upon IS researchers to join their colleagues in finance and accounting to develop a common set of metrics for assessing the performance of IT investments at virtually any level of analysis.

Toward this goal, the first and most difficult step is to assess how existing revenue can be allocated. This paper's primary goal is to stimulate a debate and future research on measuring the returns on IT investment through the allocation of revenue to productive assets. Given the inherent difficulty in developing a solid theory and a corresponding operationalization for unambiguously allocating revenue across the firm, this paper aims to offer a preliminary set of guidelines for formulating the problem of allocating revenue at any level of analysis. In doing so, it aims to entice future research to seek answers in terms of how IT-driven revenue can be accurately traced back to its origins, hoping to stimulate the development of new approaches to solve the more general problem of estimating and convincingly proving the return of IT investments.

The first debate will focus on the conceptual underpinnings of how value can be traced back to its origins, whether this is at the process, function or firm level. The proposed KBV theory basis and other theoretical lenses could be debated for their superiority in conceptualizing the performance impacts of IT investments at various levels of analysis. While the proposed KBV approach is uniform for all levels of analysis, it may be possible that different theories may be more appropriate for different levels of analysis. A second debate could revolve around the operationalization of the various theories for revenue allocation. These two interrelated debates would help establish superior theories and operationalizations for allocating revenue due to IT investments, thereby helping managers, analysts, and investors to predict and assess the value-potential of IT.

References

Alavi, M. (2000) "Managing Organizational Knowledge," In R. W. Zmud (Ed.), *Framing the Domains of IT Management*. Cincinnati, OH: Pinnaflex.

Alavi, M. and D.E. Leidner (2001) "Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues," *MIS Quarterly* (*25*)1, pp. 107-136.

Amram, M. and N. Kulatilaka (1999) *Real Options: Managing Strategic Investment in an Uncertain World*. Boston: Harvard Business School Press.

Ba, S., J. Stallaert, and A. Whinston (2003) "Optimal Investment in Knowledge within a Firm Using a Market Mechanism," Management *Science* (12)1, pp. 200-214.

Barua, A., H.C. Kriebel and T. Mukhopadhyay (1995) "Information Technologies and Business Value: An Analytic and Empirical Investigation," *Information Systems Research* (6)1, pp. 3-23.

Barua, A., S. Lee, and A. Whinston (1996) "The Calculus of Reengineering," *Information Systems Research* (7)4, pp. 409-428.

Barua, A. and T. Mukhopadhyay (2000) "Information Technology and Business Performance: Past, Present, and Future," In R. W. Zmud (Ed.), *Framing the Domains of IT Management*. Cincinnati, OH: Pinnaflex.

Bannan, K. (2001) "Measure for Measure," *e-CFO,* Special Summer Issue, pp. 58-59. Becerra-Fernandez, I. and R. Sabherwal (2001) "Organizational Knowledge Management: A Contingency Perspective," *Journal of Management Information Systems (*18)1, pp. 23-55.

Benaroch, M. and R. Kauffman (1999) "A Case for Using Real Options Pricing Analysis to Evaluate Information Technology Project Investments," *Information Systems Research,* (10)1, pp. 70-86.

Birchard, B. and A. Nyberg (2001) "On Further Reflection: Do EVA and Other Value Metrics Still Offer a Good Mirror of Company Performance?" *CFO Magazine, March* 1, 2001*.*

Bharadwaj, A. (2000) "A Resource-Based Perspective on Information Technology Capability and Firm Performance: An Empirical Investigation," *MIS Quarterly,* (24)1, pp. 169-196.

Brynjolfsson, E. and L. Hitt (1996) "Paradox Lost? Firm-level Evidence on the Returns on Information Systems Spending," *Management Science,* (42)4, pp. 541-558.

Brynjolfsson, E. and L. Hitt (1998) "Beyond the Productivity Paradox," *Communications of the ACM,* (41)8, pp. 49-55.

Brynjolfsson, E. and S. Yang (1996) "Information Technology and Productivity: A Review of the Literature," *Advances in Computers,* (43)2, pp. 179-214.

Chappell, A. (1999) "Is Knowledge Transfer the Key to Retention? " *The Club Insider, May*, pp. 16-20.

Cover, T. and J. Thomas (1991) *Elements of Information Theory*. New York: John Wiley & Sons.

Devaraj, S. and R. Kohli (2003) "Performance Impacts of Information Technology: Is Actual Usage the Missing Link?" *Management Science* (49)3, pp. 273-289.

Dos Santos, B., K. Peffers and D.C. Mauer, (1993) "The Impact of Information Technology Investment Announcements on the Market Value of the Firm," *Information Systems Research* (4)1, pp. 1-23.

Edvinsson, L. and M. Malone (1997) *Intellectual Capital*. New York: Harper Business.

El Sawy, O. (2001) *Redesigning Enterprise Processes for e-Business.* Boston: McGraw-Hill.

El Sawy, O., A. Malhotra, S. Gosain, and K. Young (1999) "IT-Intensive Value Innovation in the Electronic Economy: Insights from Marshall Industries," *MIS Quarterly,* (23)3, pp. 305-335.

Grant, R. M. (1996) "Toward a Knowledge Based Theory of the Firm," *Strategic Management Journal* (17), pp. 109-122.

Hitt, L. and E. Brynjolfsson (1996) "Productivity, Business Profitability and Consumer Surplus: Three Different Measures of Information Technology Value," *MIS Quarterly,* (20)2, pp. 144-162.

Housel, T. and A. Bell (2001) *Managing and Measuring Knowledge*. Boston: McGraw-Hill.

Housel, T., O. El Sawy, J. Zhong, and W. Rodgers (2001) "Measuring the Return on Knowledge Embedded in Information Technology,*" Proceedings of the 21st International Conference on Information Systems*, New Orleans, LA, pp. 16-19.

Housel, T. and S. Hom (1999) "Knowledge Management for the Telecommunications Industry," Professional Education International, Inc., *International Engineering Consortium*, Chicago, IL.

Housel, T. and V. Kanevsky (1995) "Re-Engineering Business Processes: A Complexity Theory Approach to Value Added," *INFOR,* (33)4, pp. 248-262.

Im, K., K. Dow, and V. Grover (2001) "Research Report: A Reexamination of IT Investment and the Market Value of the Firm – An Event Study Methodology," *Information Systems Research* (12)1, pp. 103-117.

Jarvenpaa, S. and D. Leidner (1998) "An Information Company in Mexico: Extending the Resource-based View of the Firm to a Developing Country Context," *Information Systems Research,* (4)9, pp. 342-361.

Johnson, H. (1992) *Relevance Regained: From Top-Down to Bottom-Up Employment*. New York: The Free Press.

Johnson, H. and R. Kaplan (1987) *Relevance Lost: The Rise and fall of Management Accounting*. Boston: Harvard Business School Press.

Kanevsky, V. and T. Housel (1998) "The Learning-Knowledge-Value Cycle" in *Knowing in Firms: Understanding, Managing, and Measuring Knowledge*. G. Von Krogh, J. Roos, and Kleine, D. (Eds), New York: Sage.

Kaplan, R. and D. Norton (1996) *The Balanced Scorecard*. Boston: Harvard Business School Press.

Kogut, B. and U. Zander (1992) "Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology," *Organization Science* (3)3, pp. 383-397.

Kogut, B. and U. Zander (1996) "What do Firms do? Coordination, Identity, and Learning," *Organization Science* (7), pp. 502-518.

Kohli, R., and S. Devaraj (2003) "Measuring Information Technology Payoff: A Meta-Analysis of Structural Variables in Firm-Level Empirical Research," *Information Systems Research* (14)2, pp. 127-145.

Lenatti, C. (2003) "Grinding Away on ROI," *CFO – IT,* (8) 19, pp. 22-29.

Leonard-Barton, D. (1992) "Core Capabilities and Core Rigidities: A Paradox in Managing New Product Development," *Strategic Management Journal* (*13*)1, pp. 111-125.

Melville, N., K. Kraemer, and V. Gurbaxani (2004) "Review: Information Technology and Organizational Performance: An Integrative Model of IT Business Value," *MIS Quarterly* (28)2, pp. 283-322.

Mendelson, H. (2000) "Organizational Architecture and Success in the Information Technology Industry," *Management Science* (46)4, pp. 513-529.

Milgrom, P., Y. Qian and J. Roberts (1991) "Complementarities, Momentum, and the Evolution of Modern Manufacturing," *American Economic Review* (81)2, pp. 84-88.

Milgrom, P. and E.B. Roberts (1995) "Complementarities and Fit: Strategy, Structure, and Organizational Change in Manufacturing," *Journal of Accounting and Economics* (19)2, pp. 179-208.

Nahapiet, J. and S. Ghoshal (1998) "Social Capital, Intellectual Capital, and the Organizational Advantage," *Academy of Management Review* (*23*)2, pp. 242-266.

Nonaka, I. (1991) "The Knowledge-Creating Company," *Harvard Business Review,* (69), pp. 96-104.

Nonaka, I. (1994) "A Dynamic Theory of Organizational Knowledge Creation," *Organization Science (5)1,* pp. 14-37.

Nonaka, I. and H. Takeuchi (1995) "*The Knowledge-Creating Company*," New York: Oxford University Press.

Polanyi, M. (1975) "Personal Knowledge," In M. Polanyi & H. Prosch (Eds.), *Meaning*, Chicago: University of Chicago Press, pp. 22-45.

Ray, G., W.A. Muhanna, and J.B. Barney (2005) "Information Technology and the Performance of the Customer Service Process: A Resource-Based Analysis," *MIS Quarterly*, (forthcoming).

Richardson, V. and R.W. Zmud (2002) "Systematic Investor Biases Regarding Stock Market Returns Following Information Technology Expenditures*,*" working paper, University of Oklahoma.

Rodgers, W. and T. Housel (2001) "Investment Decision Making in the High Technology Industry: Implications for the Accounting Profession," *Proceedings of the European Accounting Association Annual Congress*, pp. 456-471.

Sambamurthy, V. (2000) "Business Strategy in Hyper competitive Environments: Rethinking the Logic of IT Differentiation," In R. W. Zmud (Ed.), *Framing the Domains of IT Management*. Cincinnati, OH: Pinnaflex.

Strassman, P. (1997) *The Squandered Computer*. New Haven: The Information Economics Press.

Strassman, P. (2000a) "Accumulating Knowledge Efficiency," *Knowledge Management,* February, http://www.kmmag.com.

Strassman, P. (2000b) "In Search of Knowledge Capital". *Knowledge Management*, September, http://www.kmmag.com.

Subramani, M.R. and E. Walden (2002) "The Impact of E-commerce Announcements on the Market Value of Firms," *Information Systems Research*, (12)2, pp. 135-154.

Tsoukas, J. (1996) "The Firm as a Distributed Knowledge System: A Constructionist Approach," *Strategic Management Journal* (17)1, pp. 11-25.

Zander, U. and Kogut, B. (1995) "Knowledge and the Speed of Transfer and Imitation of Organizational Capabilities," *Organization Science* (6)1, pp. 76-92.

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