Investment in Enterprise Resource Planning: Business Impact and Productivity Measures

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ABSTRACT: Enterprise Resource Planning (ERP) software systems integrate key business and management processes within and beyond a firm's boundary. Although the business value of ERP implementations has been extensively debated in trade periodicals in the form of qualitative discussion or detailed case studies, there is little large-sample statistical evidence on whether the benefits of ERP implementation exceed the costs and risks. With multiyear multi-firm ERP implementation and financial data, we find that firms that invest in ERP tend to show higher performance across a wide variety of financial metrics. Even though there is a slowdown in business performance and productivity shortly after the implementation, financial markets consistently reward the adopters with higher market valuation (as measured by Tobin's q). Due to the lack of mid- and long-term post-implementation data, future research on the long-run impact of ERP is proposed.

KEY WORDS AND PHRASES: Enterprise Resource Planning systems, information technology, productivity, productivity analysis, ROI.

ENTERPRISE RESOURCE PLANNING (ERP) software systems encompass a wide range of software products supporting day-to-day business operations and decision-making. ERP serves many industries and numerous functional areas in an integrated fashion, attempting to automate operations from supply chain management, inventory control, manufacturing scheduling and production, sales support, customer relationship management, financial and cost accounting, human resources, and almost any other data-oriented management process. ERP systems have become increasingly prevalent over the last 10 years [36]. The license/maintenance revenue of ERP market was \$17.2 billion in 1998, it is expected to be \$24.3 billion in 2000, and ERP systems have been implemented in over 60 percent of multinational firms [39]. This market also cuts across industries—for example, two of the world's best-known software companies, IBM and Microsoft, now run most of their business on software neither of them makes, the SAP R/3 ERP package made by SAP AG [36].

The appeal of the ERP systems is clear. Although most organizations typically had software systems that performed much of the component functions of ERP, the standardized and integrated ERP software environment provides a degree of interoperability that was difficult and expensive to achieve with stand-alone, custom-built systems [23, 36]. For example, when a salesperson enters an order in the field, the transaction can immediately flow through to other functional areas both within and external to the firm. The order might trigger an immediate change in production plans, inventory stock levels, or employees' schedules, or lead to the automated generation of invoices and credit evaluations for the customer and purchase orders from suppliers. In addition to process automation, the ability of ERP systems to disseminate timely and accurate information also enables improved managerial and worker decision-making. Managers can make decisions based on current data, whereas individual workers can have greater access to information, enabling increasing delegation of authority for production decisions as well as improved communications to customers [36].

Implementation of ERP systems requires a substantial investment of time, money, and internal resources [3, 50] and is fraught with technical and business risk [2]. A typical ERP installation has a total cost of about $15 million [36, p. 6] and costs can be as high as two to three percent of revenues [20].[1] Installation takes between one and three years (21 months on average), with benefits starting to accrue in an average of 31 months [30, 36]. ERP implementations are also known to be unusually difficult, even when compared to other large-scale systems development projects. Part of this difficulty is due to the pervasiveness of the changes associated with ERP, the need for simultaneous process redesign of multiple functional areas within the firm, and the need to adapt processes to the capabilities of the software.[2] There is also a high degree of managerial complexity of these projects. Although ERP systems are packaged software applications, the majority (~60 percent) of project cost is devoted to setup, installation, and customization of the software, services typically provided by outside consultants such as Accenture or EDS [18, 38].[3] Success or failure hinges on the effective collaboration among these teams, the business knowledge of internal business experts and the technical skills of outside IT consultants [38]. Numerous cases document ERP implementation failures [17, 29], some with disastrous results.[4]

Given the scale of ERP implementation projects as well as the possibility for both large successes and failures, it is reasonable to expect that ERP deployment has a significant and measurable effect on firm performance. Although both costs and potential benefits are high, it is not clear whether the net effect results in higher productivity for the firm. In addition, because implementation is a difficult and uncertain process, firms that are successful in implementing ERP may gain competitive advantage over other firms that are unwilling or unable to make similar changes, thus increasing the value of the firm.

To date, most of the documentation of the benefits of ERP has been in the form of individual case studies (for example [16, 18, 24, 30, 49]), product testimonials (such as SAP press releases), and industry surveys [1, 32]. In this paper, we systematically study the productivity and business performance effects of ERP using a unique data set on firms that have purchased licenses for the SAP R/3 system, the most widely adopted ERP package. Our goal is to better understand the economics of ERP implementations specifically, and more broadly, contribute to the understanding of the benefits of large-scale systems projects.

Literature Review

THIS WORK DRAWS ON TWO STREAMS of previous literature: the work on the business value of information technology and the more specialized literature on the value of ERP implementations. In this section, we briefly survey each of these areas as they apply to our analysis.

Business Value of Information Technology

There is an extensive literature investigating the business impact of information technology (IT) using a wide variety of methodologies and different levels of analysis. Although work at the economy-wide level has typically shown equivocal results until very recently (see, for example [37]), research at the firm-level has demonstrated that IT investment has a significant effect on productivity levels, productivity growth, and stock market value of firms [13]. Other research has also found some positive effects on internal performance metrics such as inventory turnover [4].

Although much is known about the general effect of information technology on productivity, there is less understanding of the value of specific IT applications and the factors that make a particular project or system more effective. Previous studies found that IT automation of postal sorting and toll collection had a significant effect on productivity [34, 35]. Benefits were also found in research of the plant level for automated machine tools [28] and for "advanced manufacturing technologies," most of which are computer-related [19]. Brynjolfsson et al. [15] found that certain organizational practices, such as the increased use of skilled workers and decentralized and team-based organizational structures, increased the value of IT investments. Using survey data, Brynjolfsson and Hitt [8] found that firms that invested more heavily in business process redesign and devoted more of their IT resources to increasing customer value (such as, quality, timeliness, convenience) had greater productivity and business performance. Parallel results have been found for ERP implementations where it has been shown that organizational characteristics affect the value received from ERP implementation [42]. All of this research suggests that there can be positive benefits from the automation, process redesign activities, and increased timeliness or output quality associated with successful ERP system deployment, although these effects in the specific context of ERP have not been previously studied statistically.

Impact of ERP Implementation

There is a small but growing literature on the impact of ERP systems; the majority of these studies are interviews, case studies, a collection of case studies, or industry surveys (see, for example [1, 17, 31, 32, 43]). McAfee [30] studied the impact of ERP systems on self-reported company performance based on a survey of 101 U.S. implementers of SAP R/3 packages. Participating companies reported substantial performance improvement in several areas as a result of their ERP implementation, including their ability to provide information to customers, cycle times, and on-time completion rates. Based on an information processing view of the firm [22], Gattiker and Goodhue [23] group the literature of ERP benefits into four categories: (1) improve information flow across subunits through standardization and integration of activities, (2) enable centralization of administrative activities such as account payable and payroll, (3) reduce information systems (IS) maintenance costs and increase the ability to deploy new IS functionality, and (4) enable a transformation from inefficient business processes toward accepted best of practice processes. They also show that firm- and site-specific differences may be critical drivers of implementation outcome.

The above studies on the impact of ERP systems suggest that there are potentially substantial benefits for firms that successfully implement ERP systems, although there is little in terms of broad sample statistical evidence [41]. However, this general area has begun to attract more attention from academics (see, for example [21, 41, 44]).

Data, Methods, and Hypotheses

Data

OUR ANALYSIS LEVERAGES AND EXTENDS existing data on information technology and productivity originally used by Brynjolfsson and Hitt [13] for the study of IT and productivity growth.[5] We combine this database on IT and other financial measures with new data on the adoption of ERP by publicly traded firms. We use two sample frames for this analysis—some analyses are performed using all publicly traded firms on Compustat; other analyses are limited to large firms (defined as the Fortune 1000) where complementary data on IT usage is available. Details on these data sources appear below.

ERP Adoption

Our primary data and unique data source is a record of all license agreements for the SAP R/3 system sold by SAP America over the time period 1986 to 1998—this is essentially a sales database used to record the number of licenses sold. When a firm purchases a license from SAP, pricing is based on the number of "seats" (in addition to an up-front basic license fee), which represent the number of simultaneous users that the system will support. The SAP system is modular, in the sense that each of the functional modules (such as, production planning, sales and distribution, financial accounting, human resources) can be installed or not at the firms' discretion without additional licensing fees, but SAP does track which modules are installed.

Our data includes the name of the firm that purchased the license, the location where the system was installed, the date of the original purchase, the date the installation was completed and the system went live, and the modules that are active for each location. Although there are over 40 modules or variations of modules in the system, they can be broadly grouped into five primary areas: manufacturing, finance, human resources, project management, and IS.[6] We will utilize these groupings for some of our analyses. The data is maintained at the level of individual sites, whereas our other data is at the level of the firm—we therefore aggregate the data to the firm level for our analysis (details of the aggregation are specific to each analysis and will be described later). We then match the aggregate data to Compustat and the Computer Intelligence database (described below). This necessarily limits the analysis to firms that are publicly traded in the United States, but using this method we are able to match 70 percent of all firms in the database.

Although these data have not been previously available to academic researchers and thus have not been validated in previous work, these data are used for real operational decisions at SAP and we therefore believe that they are extremely accurate in terms of covering all SAP sales. However, there are a number of concerns about using these data for the analysis of ERP adoption and performance. Probably the most serious issue is that we only have adoption data for SAP, but not for other ERP vendors. Given that SAP has over 75 percent of the ERP market today (higher historically) at large firms (see [45] and other sources),[7] we are confident that we capture most of the ERP installations. However, when we do comparisons between adopters and the relevant population of firms (either all publicly traded firms on Compustat or the Fortune 1000) there will be firms that are adopters of other ERP packages. If we assume that the benefits of the different ERP packages are similar across vendors, this type of data error will tend to diminish the apparent differences between our measured adopters and nonadopters, biasing our model coefficients toward zero. Thus, care must be made in interpreting insignificant results, as lack of effect is not completely distinguishable from data error. However, some large firms implementing SAP R/3 also implement other ERP packages to take advantage of the "best-of-breed" of different vendors, suggesting that our data set might closely approximate the majority of ERP implementers, though not necessarily the extent of implementation. This limitation is less of a difficulty for the portions of our analysis that are restricted to SAP adopters only, although the issue of adoption of competing packages is still a concern.

A second concern is data matching. Our unit of analysis is the firm level, yet a firm may only partially adopt the R/3 system in at least two ways. They may only deploy the system in some but not all physical locations and they may only deploy a small subset of the system in any given installation. We therefore examine both the adoption decision generally (buy SAP R/3 or not) as well as the extent of adoption by examining which modules were implemented. Unfortunately, we are unable to measure "seats" sold due to idiosyncrasies on how the sales data are kept at SAP, making it difficult to estimate the exact extent of firm-level utilization. There are also some data-matching problems with firms that operate internationally so we have also performed robustness checks including and excluding installations at non-U.S. subsidiaries with similar results. Finally, a firm may implement part but not all of the system. For our purposes, this creates a measurement advantage because it enables comparisons of the value of different modules as well as the gains (if any) of exploiting the modularity of the product versus implementing individual modules in a stand-alone fashion.

Financial Performance

We utilize Standard and Poor's Compustat II database to construct various measures necessary to calculate productivity, stock market valuation, and firm performance using standard approaches utilized in previous work on productivity generally [25] and specifically the business value of IT [13, 14, 27]. Details on the data construction are provided in Table 1. Measures are constructed for firm value added, capital stock, labor input, industry, total stock market valuation, size, debt-equity ratios, and a number of standard performance ratios such as return on equity, return on assets, and other accounting ratios such as inventory turnover rate (see the section "Results, Interpretation, and Limitations" for more details).

Information Technology Use

In some analyses we utilize the Computer Intelligence InfoCorp (CII) database for a metric of information technology use. CII conducts a telephone survey to inventory specific pieces of IT equipment by site for firms in the Fortune 1000 (surveying approximately 25,000 sites). For our study, CII aggregated types of computers and sites to get firm-level IT stocks. They calculated the value of the total capital stock of IT hardware (central processors, PCs, and peripherals) as well as measures of the computing capacity of central processors in millions of instructions per second (MIPS) and the number of PCs. The IT data do not include all types of information processing or communication equipment and are likely to miss a portion of computer equipment that is purchased by individuals or departments without the knowledge of IS personnel or are owned or operated off-site. The IT data also exclude investments in software and applications. However, for our purposes they are broadly indicative of a firm's overall use of IT, which, although not perfect, is useful for discriminating between high and low users of IT.

Descriptive Statistics

Our primary data (Compustat and ERP adoption) span the 1986–1998 time period, resulting in 24,037 firm-years observations for the entire population of firms, including 4,069 firm-years of data for firms that have implemented one or more SAP modules (including about 350 unique firms). When we restrict the sample to firms that also have complete IT data from CII, the population is reduced to 5,603 firm-years with 1,117 with SAP implementations (see Table 2).

Analytical Methods and Hypotheses

We examine the effect of ERP adoption on productivity, firm performance, and stock market valuation using several different models that have been applied in previous work on IT and productivity [14, 15, 27]. Using both the cross-section and time series component of our data, we can examine the difference in performance of firms (measured in a variety of ways) that adopted ERP versus those that did not. Using the longitudinal dimension we can examine the relative performance of firms before, during, and after implementation to examine how the effect of ERP implementations appears over time. Finally, we can use additional data on modules implemented to understand how the extent of implementation affects performance.

Table 1. Data Construction of Financial Performance Measures

Ratio	Definition	Interpretation
Labor productivity	Sales/number of employees	*Profitability measure:* High ratio indicates more productivity per employee
Return on assets	Pretax income/assets	*Profitability measure:* High ratio indicates efficient operation of firm without regard to its financial structure
Inventory turnover	COGS/inventory	*Activity measure:* High ratio indicates more efficient inventory management
Return on equity	Pretax income/equity	*Profitability measure:* High ratio indicates higher returns accruing to the common shareholders
Profit margin	Pretax income/sales	*Profitability measure:* High ratio indicates high profit generated by sales
Asset turnover	Sales/assets	*Activity measure:* High ratio indicates high level of sales generated by total assets.
Account receivable turnover	Sales/account receivable	*Activity measure:* High ratio indicates effective management of customer payment
Debt to equity	Debt/equity	*Debt and solvency measure:* The higher the debt ratio, the riskier the firm
Tobin's q	Market value/book value	High ratio indicates stock market is rewarding the firm

Table 2. Sample Statistics

	Full population	Fortune 1000/ CII population
Total observations	24,037	5,603
Observations of ERP adopters	4,069	1,117

Empirical Methods: Performance Analysis

We use three basic specifications for the analysis of the performance impact of ERP adoption: performance ratios, productivity (production functions), and stock market valuation (Tobin's q). Comparable to common research approaches in the management literature and some of the literature on the productivity of IT, we estimate regressions of various measures of financial performance. The general form of the estimating equation is

$$\begin{aligned}\log(\text{performance ratio numerator}) &= \text{intercept} \\ &+ \log(\text{performance ratio denominator}) \\ &+ \text{adoption variables} + \text{year controls} + \text{industry controls} + \varepsilon.\end{aligned} \tag{1}$$

We chose to model the numerator of the performance ratio as the dependent variable with a control for the denominator on the right-hand side. This has the advantage that it provides more flexibility in the relationship between the numerator and denominator while retaining the interpretation as a performance ratio.[8] Various performance ratios are compared as they capture different aspects of firm performance, both in terms of bottom-line profitability (such as return on assets) or measures of firm activities that in turn drive performance (such as inventory turnover rate). We include separate dummy variables for each year to capture transitory, economy-wide shocks that effect performance. For instance, the time variables remove the upward trend in the stock market that occurred over our sample period, thus avoiding possible spurious correlation between stock market growth and increasing diffusion of ERP. We also control for industry (at the "1 ½ digit" SIC level)[9] to remove variation in performance ratios due to idiosyncratic characteristics of the production process of different industries.

These types of analyses have the advantage that they can capture a wide variety of different aspects of value and are commonly used in studies that seek to assess firm performance. Their primary disadvantage is that the model specification does not have a strong theoretical grounding, and thus should be interpreted as correlations rather than estimates of an econometric model. To avoid these concerns, there are two other approaches commonly employed to measure firm performance: productivity regressions and Tobin's q analysis.

Productivity regressions are based on the economic concept of production functions. Firms are assumed to have a production process represented by a functional form of $f(\cdot)$ that relates output (in our case value added, which is sales minus materials, designated as VA) to the inputs the firm consumes (capital, *K;* labor, *L*). It is common to also include controls for time and industry in this analysis as well. The most commonly used functional form for the production function is the Cobb-Douglas function, which has the advantages of both simplicity and empirical robustness for the calculation of performance differences [7, 9, 10, 11, 12, 48]. In a production function, the intercept term in a log-log regression has a special interpretation, commonly called "multifactor productivity." This metric is essentially a ratio of output to an index of inputs a firm consumes. To capture differences in performance, additional terms can simply be added to the Cobb-Douglas production function in its log-log form whose coefficients can be interpreted as percentage differences in productivity. This yields an estimating equation of the following form:

$$\log VA = \text{intercept} + \text{adoption variables} + a_1 \log K + a_2 \log L + \text{year controls} + \text{industry controls} + \varepsilon. \tag{2}$$

This type of analysis captures the productivity impact of various aspects of the adoption decision with a somewhat more rigorous foundation than the performance regressions. On the other hand, because a production function is a short run measurement framework, it may miss some advantages that accrue to the firm over time. That is, although a production function will capture productivity changes induced by ERP adoption, it has no way of capturing the future gains (which could substantially exceed the current gains) that will accrue to the firm.

An alternative approach is to utilize stock market data to value investments in ERP. To the extent that ERP implementation creates value and that investors are sufficiently informed to place some estimate on this value, the stock market will capture the current as well as expectations of future benefits that the firm will receive (see a full discussion of the interpretation of Tobin's q in Brynjolfsson and Yang [14] and the references therein). In addition, because investor expectations can incorporate intangible benefits of IT investment that are not well captured in production function analyses, market value-based approaches may better capture the total benefit of ERP implementation. As a result, analyses of Tobin's q can often show greater statistical power than approaches that rely on production functions [13]. For our work, we adopt a simplified version of the specification of Brynjolfsson and Yang [14], which relates the market value of the firm to the assets that it uses. We also include additional terms to capture the shifts in overall market value due to ERP adoption, and include time and industry dummy variables as before. Thus, we have:

$$\log(\text{market value}) = \text{intercept} + \text{adoption variables} + a_1 \log(\text{book value}) + a_2 \text{IT capital} + \text{year dummies} + \text{industry dummies} + \varepsilon. \tag{3}$$

It is important to note that all these analyses capture the benefit of ERP averaged over a wide variety of firms and projects. Clearly, not all projects will be successful, whereas others will succeed well beyond expectations. Thus, care should be taken interpreting our results as an average performance measurement across multiple firms, recognizing that there may be substantial variance for individual firms around this value.

Empirical Methods: Incorporating Adoption into Performance Measurement

Our previous discussion suggests that firms that adopt ERP systems should differentiate themselves from competitors, due to both the productivity benefits accruing for ERP use as well as an implicit barrier to entry created by the difficulty of successful ERP adoption. On average, if firms were behaving rationally, we would expect the net relationship between ERP implementation and performance to be nonnegative, and strictly positive if indeed barriers to adoption are significant. Our base hypothesis is thus:

> *H1: Firms that adopt ERP systems will show greater performance as measured by performance ratio analysis, productivity, and stock market valuation.*

This is implemented empirically by incorporating a dummy variable, which is zero if the firm is a nonadopter of ERP over our entire sample period, and one if the firm adopts ERP into various types of performance, valuation, or productivity estimating equations. We explore variants of these specifications by allowing this variable to represent the extent of adoption (number of modules, and so on) in addition to the general adoption decision. Note that our empirical formulation will enable us to identify differences in performance between ERP adopters and those that do not, but cannot necessarily distinguish the ERP adoption decision itself from other changes that may have occurred concurrently or are otherwise correlated with the choice to adopt ERP. In other words, if there are conditions or factors that affect performance that are also correlated with ERP adoption, our results may be adversely affected (see further discussion in the limitations section); if there are simply other factors that affect performance but are not correlated with the ERP adoption, or can be removed by suitable control variables for time, size, industry, and so on, decision, this decreases the precision of our results but does not introduce bias.

An alternative approach to gauge the value of adoption is to also compare the firm to itself over time. This has two specific advantages: first, it enables better control for firm heterogeneity by looking at changes over time (for example, if "good" firms tend to adopt ERP systems for nonproductive reasons, that will still appear as positive benefits in tests of H1). In addition, ERP systems have significant risks and difficulties that are likely to be encountered during the implementation process that may make productivity decline during and perhaps for some time after the implementation is complete. Survey work (discussed in the introduction) suggested that the payback of

ERP investments may not begin to accrue for two years or more after the implementation has started. Moreover, Austin and Cotteleer [2], in their survey of ERP implementation risks, found that the magnitude of organizational risk and business risk dominate technical risk—thus, one might expect risks to persist even after the technical component of the project has been completed. This suggests a second hypothesis:

H2a: There is a drop in performance during ERP implementation as measured using performance ratios and productivity regressions.

H2b: There is a continued drop in performance shortly after ERP implementation as measured using performance ratios and productivity regressions.

Given the recency of our data, as well as the recency of the rapid growth in ERP adoption, we are unable to test a logical additional hypothesis that productivity recovers and possibly exceeds previous productivity after the implementation is complete since our data is sparse following implementation.[10] However, the stock market data should provide a useful indicator of whether or not long run productivity will increase. The prediction is clear for the post-implementation analysis—firms that successfully complete implementation should receive a significant boost in market valuation representing both the future gains as well as the successful resolution of implementation risks. The market value of the implementation period itself is more uncertain as it includes the offsetting effects of potential future gains of a successful implementation against the possibility of implementation failure. We therefore (optimistically) hypothesize that

H3a: There is an increase in stock market valuation at the initiation of an ERP implementation.

H3b: There is an increase in stock market valuation of a firm at the completion of ERP implementation.

These hypotheses can be tested by incorporating two additional variables that segment the time period for ERP adopters in the performance analysis:

Begin_Impl: is one at the year of first ERP implementation and remains one afterward. It is zero prior to any implementation.

End_Impl: is one at the year when first ERP implementation is finished and remains as one afterward. It is zero prior to any completion.

Using estimates of the coefficients on these variables we can compute the productivity difference during implementation (the direct coefficient on Begin_Impl), the productivity after implementation is complete (the sum of the coefficients on Begin_Impl and End_Impl), or the difference in productivity from the implementation period to the end of implementation (the coefficient on End_Impl). These estimates can be calculated restricting the sample to only firms that are adopters, to get a pure estimate of the change in firm productivity, or pooled with nonadopters to gain a greater contrast between firms in different stages of implementation and nonadopters.

Empirical Methods: Economies of Scope and Scale in ERP Adoption

It is believed that different functional modules of an ERP package will work in harmony if implemented concurrently. Functional modules from the same vendor are strongly preferred due to reduced integration cost across disparate functional modules. In addition, tight integration of the various functional modules allows a greater degree of process automation of routine tasks as well as more comprehensive data analysis and reporting capabilities to improve discretionary management decisions. Indeed, the key selling point of ERP versus a collection of functionally specific specialized applications is the value of enterprise-wide software integration.

However, at some level it is also possible that diseconomies set in—greater implementation risk, larger support costs, hardware costs, and other technical constraints (especially response times) may hinder the successful use of the application. At greater levels of integration, minor user errors can rapidly propagate and have enterprise-wide effects. To capture the extent of implementation we examine which modules the firm implemented, using our broad grouping of all modules into the five major categories (manufacturing, finance, project management, human resources, and IS).

Ideally, one would like to use a general externally validated classification system to capture the extent of implementation. Unfortunately, the only relevant system, the APICS ABCD classification for conventional MRP performance measures (for example [33]), is not readily applicable for this analysis since we have both manufacturing and service firms (the latter typically do not have manufacturing or inventory management issues). Given that the service firms in our sample implement manufacturing-related components of the system, this is more of a theoretical concern.[11] However, more important, according to the APICS ABCD classification for MRP systems, more than 90 percent of the firms would fall into Class A since they implemented ERP, with less than 2 percent fitting into the remaining classes (other firms adopt nonmanufacturing modules in various combinations, which do not match the APICS classification).[12] As a result, we chose to develop a classification system based on the actual patterns of usage of the various SAP modules that discriminates among the various levels of ERP installation. An analysis of patterns of implementation in these data shows that the vast majority of firms (> 90 percent) implement one of four common module combinations—we label these as different implementation *Levels*. We describe a firm that has implemented any single module or an unusual combination of two modules as Level 0. Less than 10 percent of the firms fall into this category. Firms that implement the core manufacturing, finance, and IS modules are Level 1. Those that have Level 1 functionality, which also implement project management, are Level 2A and those that have Level 1 functionality, which also implement the human resources module, are Level 2B. Finally, firms that implement all five categories of modules are Level 3. Using this system we can describe our remaining hypotheses:

H4a: The benefits of ERP are increasing in the degree of implementation (Level).

If, however, the diseconomies of module scope described above are relevant over the level of implementation employed by most firms, we may also observe:

H4b: At some level of implementation the benefits of increased module integration may decline (as coordination costs or other diseconomies set in).

Results, Interpretation, and Limitations

In this section we report results on our analyses comparing adopters to nonadopters on a variety of performance metrics, comparing firm performance before, during, and after adoption, modeling the effect of various adoption levels, and then the limitations.

Comparison Between Adopters and Nonadopters

Table 3 reports our basic regression results using the regression formulation described in Equation (1). Different measures of performance are regressed on an indicator variable of ERP adoption and controls for industry, size, and time. Each column of Table 3 represents a different performance measure regression.

Overall, we find that, controlling for industry, ERP adopters show greater performance in terms of sales per employee, profit margins, return on assets, inventory turnover (lower inventory/sales), asset utilization (sales/assets), and accounts receivable turnover. That is, they are generating more revenue per unit of input and managing inventories and accounts receivable more aggressively. The control variable for size is typically below one, suggesting that we are gaining some additional statistical power by utilizing Equation (1) for the analysis rather than using performance ratios as the dependent variable. Due to the large sample in the reference population, our coefficients are precisely estimated with t-statistics on the order of 20 for the various adoption measures. Given that most of our data is before and during implementation, this suggests that higher performing firms tend to adopt ERP and that their performance is at least maintained and possibly improved by ERP adoption. The effect sizes tend to be relatively large, with marginal changes ranging from 6 to 22 percent (in absolute value). In the following two sections, we will further analyze the differences in performance before and after implementation.

The only negative performance ratio is return on equity. Given that debt/equity ratios are also lower and that return on assets shows a positive effect, it is likely that the reduction in return on equity is consistent with increased use of equity financing before and during implementation, rather than a decrease in performance. If firms perceive ERP implementation to be highly risky, one might expect firms would utilize less debt financing before and during implementation. Our data does not have many points post-implementation so we cannot test whether firms increase leverage following the implementation (as would be expected when the financial risk of implementation has subsided). Thus, our results across the different metrics appear to paint

Table 3. Performance Ratio Regressions (Pooling Adopters and Nonadopters)

Dependent variable	ln(sales)	ln(pretax income)	ln(cost of goods sold)	ln(pretax income)	ln(pretax income)	ln(sales)	ln(sales)	ln(debt)
Interpretation	Labor productivity	Return on assets (ROA)	Inventory turnover	Return on equity (ROE)	Profit margin	Asset utilization	Collection efficiency	Leverage
Implementation	0.267***	0.133***	0.0777***	–0.0628***	0.0984***	0.123***	0.1955***	–0.0796**
(1 = implemented)	(0.0145)	(0.0195)	(0.0192)	(0.0164)	(0.0206)	(0.0122)	(0.0175)	(0.0235)
ln(employees)	0.891***							
	(0.0035)							
ln(assets)		0.928***				0.863***		
		(0.00442)				(0.00270)		
ln(inventory)			0.728***					
			(0.00394)					
ln(equity)				0.938***				0.852***
				(0.00346)				(0.00495)
ln(sales)					0.971***			
					(0.00488)			
ln(accounts receivable)							0.718***	
							(0.00351)	
Control variables	Industry year							
R^2	0.825	0.769	0.712	0.8407	0.744	0.8779	0.7514	0.725
Observations	24,037	24,037	24,037	24,037	24,037	24,037	24,037	24,037

Notes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

a consistent picture that ERP has positive benefits on average and that firms behave as if the project were high risk.

The results on performance are also confirmed by the regressions on productivity and Tobin's *q* (Table 4). Firms that adopt ERP are between 2.3 percent and 4.2 percent higher in productivity, depending on the specification, when we do not control for the firm's overall use of IT capital. These coefficients become 2.7 percent and 1.7 percent when we include controls for computer usage (replicating the specifications used by Brynjolfsson and Hitt [9, 10, 13])—this suggests that we are not just identifying a correlation due to the fact that adopters of ERP are also likely to be more extensive users of IT. Coefficients on the other production function factors are close to those found in previous work as well as their theoretically predicted values, lending additional credibility to these analyses.

Results of a simple Tobin's *q* model (Table 4 columns 6 and 7) echo the previous results as well. Our results suggest that firms that implemented ERP are worth approximately 13 percent more than their nonadopting counterparts, controlling for assets (size), time, and industry. Like the other analyses, this coefficient is highly significant, even when the sample is reduced to only firms in the Fortune 1000 or when we include IT capital separately in the regression—the difference becomes 2.7 percent ($t = 5.00$, $p < 0.001$).

Collectively, these results lend support to our first hypothesis—that ERP creates performance benefits—although caveats about timing and causality discussed previously certainly apply.

Prior, During, and Post-Adoption Business Impact

Table 5 reports the results restricting the sample to only adopting firms and comparing financial metrics before, during, and after implementation. Because of the small number of data points post-adoption, the post-adoption estimates should be interpreted as the effects right at the end of the implementation period, whereas the "during adoption" estimates are probably closer to the average performance over the implementation period.

Our results on performance analyses, using the same specifications shown in Table 5, consistently show that firms have higher performance during the implementation than before or after, with the exception of accounts receivable turnover, which improves both during and after implementation. There is a substantial increase across almost all metrics during adoption, with some of this gain typically disappearing in the post-adoption period. This suggests that most of the gains previously measured are due to effects during the ERP implementation rather than driven by preexisting firm characteristics. It also suggests that the paybacks begin to appear before the projects are completed—probably the most reasonable interpretation is that many of the components of an ERP adoption are completed and operational before the firm declares the project to be complete. Alternatively, it could be that many of the "belt-tightening" organizational changes such as changes in inventory policy or reduction in the number of suppliers begin to generate gains fairly quickly, even if the more

Table 4. Productivity and Market Value Regressions (Pooling Adopters and Nonadopters)

Dependent variable	ln(value added)	ln(output)	ln(value added)	ln(output)	ln(market value)	ln(market value)
Implementation	0.042***	0.023***	0.0273**	0.0174**	0.128***	0.026***
(1 = implemented)	(0.00638)	(0.00400)	(0.00786)	(0.005)	(0.00829)	(0.0052)
ln(computer capital)			0.0249***	0.009***		0.0387***
			(0.00328)	(0.002)		(0.0042)
ln(ordinary capital)	0.34***	0.182***	0.306***	0.133***		
	(0.00271)	(0.00221)	(0.00468)	(0.00373)		
ln(labor expense)	0.647***	0.29***	0.659***	0.258***		
	(0.00283)	(0.00188)	(0.00474)	(0.00317)		
ln(materials)		0.514***		0.586***		
		(0.00198)		(0.00355)		
ln(total assets)					0.9824***	0.953***
					(0.00173)	(0.00517)
Control Variables	Industry year					
R^2	0.9613	0.9849	0.9631	0.9847	0.9521	0.9414
Observations	24,037	24,037	5,603	5,603	24,037	5,603

Notes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Table 5. Performance Comparisons: Before, During, and After ERP Implementation (Sample Restricted to Adopters Only)

Dependent variable	ln(sales)	ln(pretax income)	ln(cost of goods sold)	ln(pretax income)	ln(pretax income)	ln(sales)	ln(sales)	ln(debt)
Interpretation	Labor productivity	ROA	Inventory turnover	ROE	Profit margin	Asset utilization	Collection efficiency	Leverage
Implementation started (1/0)	0.230*** (0.0460)	0.185** (0.0695)	0.1642** (0.0580)	0.0757 (0.0591)	0.1872** (0.0713)	0.0297 (0.0320)	–0.0354 (0.0421)	–0.0612 (0.0867)
Implementation completed (1/0)	0.1634** (0.0478)	–0.0734 (0.0722)	0.1258* (0.0605)	–0.0853 (0.0607)	–0.0359 (0.0731)	–0.0159 (0.0329)	0.0084 (0.0432)	0.1060 (0.0888)
ln(employees)	0.967*** (0.00640)							
ln(assets)		0.941*** (0.00903)				0.942*** (0.00417)		
ln(inventory)			0.906*** (0.00745)					
ln(equity)				0.974*** (0.00765)				0.95*** (0.0112)
ln(sales)					0.978*** (0.00961)			
ln(accounts receivable)							0.928*** (0.00551)	
Control variables	Industry year							
R^2	0.9055	0.823	0.8617	0.8765	0.8207	0.9564	0.9245	0.7663
Observations	4,069	4,069	4,069	4,069	4,069	4,069	4,069	4,069

Notes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

technical aspects of the project have not yet been completed. Performance may revert to pre-implementation levels (especially performance measured in bottom-line financial terms) either because the gains indeed are reduced due to reduced future flexibility, or may simply suggest that the gains in performance are at least partially dissipated by long-term maintenance costs. The fact that performance measures that are not affected by costs (such as accounts receivable turnover) continue to rise suggests that this indeed may be part of the explanation. However, it is important to note that even if net performance gain at the end of the period were zero, gains were still achieved by ERP implementation; firms received a substantial performance benefit for the 1.5 years of an average implementation.

Similar results are found in the productivity regressions (Table 6, columns 2, 3, 4, and 5), again using the same specifications employed in the previous section. There is a productivity gain during the implementation period, followed by a partial loss thereafter. When value added is used as the dependent variable, the gains are 3.6 percent during implementation with a loss of 4.7 percent for a net gain of –1.1 percent (t = 0.8, not significant). Results are somewhat stronger in the productivity specification with output as the dependent variable—gains of 2.4 percent offset by a smaller loss of 1.7 percent. Because ERP implementation affects the materials/output ratio of firms, it may be that the increased flexibility of including materials in the regression (rather than subtracting them from output) explains these differences—this would generally favor the output-based specification as the more accurate measure.

Interestingly, the Tobin's q results (Table 6, columns 5 and 6) are consistent with adjustment rather than productivity decline as the explanation. During the implementation period, the firm receives an additional 6.3 percent ($t = 1.75$, $p < 0.1$) market valuation. This further increases at the end of implementation by 1.6 percent ($t = 0.4$, not significant). Although this change is not significant, there is a substantial change from pre- to post-implementation (7.9 percent, $t = 2.2$, $p < 0.01$). This is consistent with H3a and H3b (market value gains follow adoption and completion) although the strength of the post-adoption effect is quite weak. However, it does suggest that the market discounts the value of ERP implementations in progress somewhat (about 20 percent of total value) relative to their long run value at completion. This is what would be expected if markets believed that there was a substantial, but not overwhelming, risk of ERP projects.[13]

A related interpretation of the Tobin's q results is that the creation of intangible organizational assets is concentrated in the implementation period. Thus, the market is not rewarding the implementation per se, but the value of changed organizational structure, business process redesign, training, and education of the workforce, and other organizational assets that are not typically captured on the balance sheet (see [15] for a discussion of this interpretation in a broader context). It could also represent an improvement in output value along intangible dimensions (service, information accuracy, timeliness), which is positively valued by the financial markets, but not well captured in the productivity analysis due to a failure of the output deflators to completely adjust for output quality.

Table 6. Productivity and Market Value: Before, During, and After ERP Implementation (Sample Restricted to Adopters Only)

Dependent variable	ln(value added)	ln(output)	ln(value added)	ln(output)	ln(market value)	ln(market value)
Implementation started (1/0)	0.036	0.024	0.021	0.025	0.0630	0.112*
	(0.0241)	(0.0168)	(0.0250)	(0.0132)	(0.0360)	(0.0476)
Implementation completed (1/0)	–0.047	–0.017	–0.069*	–0.029*	0.0161	0.0927
	(0.0246)	(0.0171)	(0.0289)	(0.0153)	(0.0364)	(0.0552)
ln(computer capital)			0.0315***	0.0111***		0.036***
			(0.00668)	(0.00355)		(0.0111)
ln(ordinary capital)	0.368***	0.111***	0.326***	0.0947***		
	(0.00821)	(0.00812)	(0.01)	(0.00762)		
ln(labor expense)	0.635***	0.281***	0.645***	0.241***		
	(0.00869)	(0.00622)	(0.011)	(0.00575)		
ln(materials)		0.612***		0.656***		
		(0.00720)		(0.0067)		
ln(total assets)					0.9805***	0.9613***
					(0.00445)	(0.0118)
Control variables	Industry year					
R^2	0.9715	0.9868	0.9740	0.9921	0.9479	0.9317

Notes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Economies of Scope in ERP Adoption

We can extend our productivity and market value specifications to investigate whether the extent of adoption—measured as the degree of functional integration—is related to measured performance. We would generally expect benefits to increase in extent of adoption, at least up to a point where risks, technological constraints, or inflexibility caused benefits to decline. To capture different implementation levels, we simply include dummy variables for each of the implementation levels (Levels 0, 1, 2A, 2B, and 3). We conduct this analysis using the full sample (including nonadopters), although the general patterns are virtually identical if you restrict the sample to ERP adopters only and compare the different levels. The baseline in the sample is nonadoption, so the coefficients on the dummy variables can be viewed as the difference between not adopting and adopting at that level.

The results are presented in Table 7. There is a consistent pattern across all three analyses (productivity with value added, productivity with output, and Tobin's q). For the most part, any ERP implementation at any level leads to increased performance, although the coefficient on Level 1 implementation (manufacturing, finance, and IS) is close to zero and sometimes negative (but not significant). Level 2 implementations generally outperform Level 1 implementations, with the human resources module (Level 2B) adding more value than the project management module (these differences are all significant at $p < 0.01$). The large boost from implementing the human resources module might be associated with a firm making increased investments in modern human resource practices. Previous research suggests that some human resources practices represent a significant form of intangible assets (leading to higher market valuation and productivity), especially when combined with investments in IT (see [13]).

Interestingly, full implementation (Level 3) actually shows a slightly reduced performance relative to 2B. This suggests that additional modules, in this case the project planning module, does not add enough value to justify the incremental complexity when four other module types are also implemented. This is true, even though it adds value on its own (the difference between Level 1 and Level 2A). Overall, we conclude that there is support for the idea that greater use of ERP components is associated with higher performance, and provide some evidence that the broadest (most modules) implementation could face diseconomies of scale.

Limitations

Like most studies on the business value of IT, our analysis is limited by both data and empirical specification concerns. Our data only covers a single ERP vendor, albeit the one with the greatest market share, which means that we may miss adoption of competing ERP packages in firms we label as nonadopters, and also misestimate the extent of adoption when some firms combine ERP packages from SAP with those of other vendors. The former concern will tend to decrease the contrast between adopters

Table 7. Productivity Effect of Different Levels of Adoption

Dependent variable	ln(value added)	ln(output)	ln(market value)
Nonadopter	0	0	0
Any module (Level 0)	0.0900***	0.0384**	0.0436***
	(0.0207)	(0.0129)	(0.0115)
Manufacturing and finance (Level 1)	–0.00231	0.00195	0.0329***
	(0.0108)	(0.00678)	(0.00601)
Management, finance, and project management (Level 2A)	0.0358***	0.0248***	0.0689***
	(0.0109)	(0.00679)	(0.00621)
Management, finance, and human resources (Level 2B)	0.0816***	0.0908***	0.0917***
	(0.0203)	(0.0127)	(0.0119)
All (Level 3)	0.0746***	0.0206**	0.0539***
	(0.0113)	(0.00710)	(0.00648)
ln(ordinary capital)	0.339***	0.182***	
	(0.00271)	(0.00221)	
ln(labor expense)	0.647***	0.290***	
	(0.00647)	(0.00188)	
ln(materials)		0.514***	
		(0.00198)	
ln(total assets)			0.982***
			(0.00174)
Control variables	Industry year		
R^2	0.961	0.985	0.952
Sample	Full (including nonadopters)	Full (including nonadopters)	Full (including nonadopters)

Notes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

and nonadopters, making it less likely we will see ERP benefits in our analysis, whereas the latter will decrease the contrast between the value of different adoption levels. Thus, although this limitation makes it difficult to interpret the results precisely, we believe that if anything, these data problems will tend to make our results more conservative. A similar argument applies for the related problem that firms that choose to adopt ERP may do so in many different ways (number of sites, modules at different sites, number of employees using the system), which will also tend to bias our results toward finding no effect of ERP due to random data error in our adoption measure.

A second data concern is sample selection. We have focused on (generally) large publicly traded firms and the results may not generalize to smaller firms. This may be an increasingly important limitation as ERP vendors increasingly target smaller enterprises. However, using this sample enables us to calculate performance using audited financial statements, a significant advantage.

Finally, the performance analysis framework we employ is subject to problems of omitted variables and reverse causality. Numerous factors affect performance in ways that are not easily observed by the researcher and these unmeasured factors can either reduce the precision of the estimates or bias the estimates in indeterminate directions. To the extent that these omitted factors are removed by control variables (such as time or industry) or are correlated with performance but not with our ERP adoption measures, they will not affect the magnitude of the results. However, they may indeed be factors that simultaneously affect performance and the decision to adopt ERP, introducing bias. It is not clear the direction of this bias—for instance, firms with large amounts of unexpected free cash flow may choose to invest more heavily in ERP yielding a positive bias, or firms in financial distress or those facing severe operational difficulties may also choose to invest in ERP yielding a negative bias. Our "before and after" analysis can control somewhat for factors that affect ERP use and performance that are constant over time (such as, organizational structure, human capital, or managerial quality), but without a detailed model of the ERP adoption decision that could identify potential instruments for instrumental variables estimation, reverse causality remains a significant concern.

Conclusion and Future Directions

Summary

DESPITE THESE LIMITATIONS, in this paper we are able to exploit newly available data to develop a unique body of results relating ERP adoption to performance in a variety of ways. Using established approaches in the literature on business performance and productivity measurement we are able to measure the contribution of ERP investments in a manner consistent across a large number of firms, providing complementary results to the extensive body of case studies on ERP performance. Moreover, because we have both time series and cross-sectional dimensions in our data, we can compare different stages of adoption and may be less immune to problems of firm heterogeneity than purely cross-sectional analyses.

We find that ERP adopters are consistently higher in performance across a wide variety of measures than nonadopters. Our results suggest that most of the gains occur during the (relatively long) implementation period, although there is some evidence of a reduction in business performance and productivity shortly after the implementation is complete. However, the financial markets consistently reward the adopters with higher market valuation both during and after the adoption, consistent with the presence of both short-term and long-term benefits.

Overall, this suggests that indeed ERP systems yield substantial benefits to the firms that adopt them, and that the adoption risks do not exceed the expected value, although there is some evidence (from analysis of financial leverage) that suggests that firms do indeed perceive ERP projects to be risky. There also appears to be an optimal level of functional integration in ERP with benefits declining at some level, consistent with diseconomies of scope for very large implementations, as one would typically expect. Although we have significant concerns about potential reverse causality in our results (partially addressed by the before-during-after analysis), our results are broadly consistent with our prior intuitions, hypotheses, and the previous research.

Contributions

This paper is one of the first papers to consider the contribution of ERP systems to performance across a large variety of firms. Although a considerable body of research has been developed on understanding the mechanisms by which ERP creates value and the difficulties in ERP implementation, few studies have been able to quantify the benefits in a manner consistent across firms. This also extends existing work on IT productivity to consider a specific and potentially high impact IT implementation, contributing to an increasing body of studies that have investigated information technology productivity issues at the project or technology level. In addition to providing some initial results on the value of ERP implementation, the general approaches we employ can provide a platform for studying how different market conditions, organizational practices, or complementary investments affect the value of ERP more closely linking economic outcomes with the available case evidence and providing a set of empirical approaches that can be augmented with additional survey or interview data to better understand the factors that affect ERP value.

From a practitioner perspective, our major contribution is showing that, despite the potentially high costs, the average ERP implementation is a productive investment. These results may aid the overall decision process regarding adoption and also help set expectations as to what stages in an ERP project the benefits are likely to become measurable. We also show that benefits may be influenced by the extent of adoption (as measured by our adoption level scale), which suggests that synergies between different components of the overall system may be important in determining ultimate value, but that at high levels of adoption, diseconomies may arise. Finally, whereas the design of our study is to analyze results at the firm level, similar approaches can be employed within firms to compare the relative performance of different installations or perform before and after comparisons.

Future Research

Although our data does not currently allow more detailed analysis of the exact pattern of adoption (due to lack of detailed data on the extent of deployment at the worker level), it would be useful to explore in much greater detail the economies or diseconomies of scope from different adoption levels to help guide project planning. In addition, the nature of our data limits our ability to examine long-term productivity effects, which would be important in better understanding the extent of time lags between costs incurred and benefits received. Finally, it would be useful to examine in more detail how firm-specific factors, such as organizational structure or human capital, affect both the cost of implementation as well as the benefits received.

These types of large-scale enterprise systems may also have a significant impact on the structure of the firm since modern ERP systems not only affect internal production costs, but can significantly alter the costs of coordination and need for relationship-specific investment to support coordination across firm boundaries (for example [26]). These two factors are central determinants of the cost and benefits of different firm structure (such as, use of markets versus hierarchies). Although there are a number of predictions in this literature about how IS affect firm boundaries, few have been able to examine in detail systems that directly affect coordination and contracting costs, enabling a much more detailed characterization about how IS may affect the structure of firms and markets in the long term.

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Notes

1. These numbers tend to be large because ERP systems have historically been adopted by large firms with large-scale implementation requirements. However, small and medium-sized enterprises that are increasingly adopting ERP have much lower implementation costs, which will tend to push the average cost downward.

2. Thomas Van Weelden, CEO of Allied Waste, noted that one of the primary concerns for abandoning their SAP implementation was, "They [SAP] expect you to change your business to go with the way the software works" [3].

3. For a typical ERP project, cost breaks down as follows: software licensing (16 percent), hardware (14 percent), consulting (60 percent), and training and other internal staff costs (10 percent).

4. The SAP-Siebel-Manugistics implementation at Hershey was three months behind schedule, and Hershey officials offered this late implementation as a partial explanation as to why Hershey missed 10 percent of its expected earnings [5]. Geneva Steel [36, pp. 39–48, 219] declared bankruptcy the day after their $8 million SAP system was implemented. FoxMeyer (a $7 billion company) planned $65 million for their SAP implementation; it claimed in litigation that SAP was one of the reasons that it had gone bankrupt, and it is suing both SAP and Andersen Consulting [40]. Numerous articles in trade periodicals reported the difficulty of use or the difficulty of implementation of ERP systems (for example [46, 47]). It is estimated that at least 90 percent of ERP implementations end up late or over budget [29].

5. These data have been used for related works in Bresnahan et al. [6], Brynjolfsson and Yang [14], and Brynjolfsson et al. [15].

6. The IS module includes application protocol interface (APIs) and other basis components, database products, business information warehousing, and related data mining technologies.

7. A presentation by SAP executives in 1996 gave the following detailed information about the user of SAP R/3 in America's Fortune 500 companies: six out of the top ten American companies; seven out of the ten most profitable companies; nine out of the ten companies with the highest market value; seven out of the top ten pharmaceutical, computer, and petroleum companies; six out of the top ten electronics companies; eight out of the top ten chemical and food companies. These numbers have been increased since then [45].

8. This formulation relies on the property that $\log(A/B) = \log(A) - \log(B)$. We thus estimate a specification that has $\log(A) = \text{intercept} + a_1\log(B) + \text{other controls}$. The other controls retain

their interpretation as change in the performance ratio and the interpretation is identical if $a_1 = 1$.

9. This divides the economy into 10 industries, which include: Mining/Construction, Process Manufacturing, High-Tech Manufacturing, Other Durable Manufacturing, Other Nondurable Manufacturing, Wholesale Trade, Retail Trade, Transportation, Utilities, Finance and Other Services.

10. An example would be the follow-up story of SAP-Siebel-Manugistics implementation at Hershey, as noted previously, where benefits have been regained in the long term (private communication, team member of Hershey SAP implementation project).

11. Clearly, our sample of SAP implementation reflects a bias toward those service firms with manufacturing operations (such as retailers with manufacturing capability) or with manufacturing-like operations (wholesalers, transportation companies). This is simply a feature of the market as opposed to an empirical concern.

12. The APICS MRP performance measure falls into four categories, often identified as ABCD, in terms of use and firm implementation. Class A represents full implementation of MRP, including linkages to the firm's financial system and human resource planning. Class B of MRP system is restricted in the manufacturing area including MPS (master production scheduling). Class C is confined only to inventory management. Class D is the lowest degree of implementation where MRP is used for tracking data only. For more details, see, for example [33, p. 7], or www.apics.org. We thank a referee for directing our attention to this.

13. For example, if an ERP project were highly risky in the sense that it provided a +2 percent productivity gain with 50 percent probability and a –2 percent loss with 50 percent probability, the market should not reward the project until after successful completion. If the numbers were +5 percent and +3 percent for success and failure, respectively, a 4 percent gain might appear upon announcement, with the remaining amount (on the order of 1 percent) appearing after successful completion. We are not able to calculate these types of figures, because our data does not distinguish successful versus unsuccessful completion, although one would typically expect a firm to continue a project until it could be deemed successful (thus, our completion metric might be highly correlated with project success).

References

1. AT Kearney. Strategic information technology and the CEO agenda. Monograph, AT Kearney, Inc., Chicago, 1996, 1998, 2000.

2. Austin R., and Cotteleer, M. Current issues in IT: Enterprise resource planning. Unpublished presentation, Harvard Business School, October 1999.

3. Bailey, J. Trash haulers are taking fancy software to the dump. *Wall Street Journal,* June 9, 1999.

4. Barua, A.; Kriebel, C.; and Mukhopadhyay, T. Information technology and business value: An analytic and empirical investigation. *Information Systems Research, 7,* 4 (April 1995), 409–428.

5. Branch, S. Hershey to miss earning estimates by as much as 10%. *Wall Street Journal,* September 14, 1999, p. B12.

6. Bresnahan, T.; Brynjolfsson, E.; and Hitt, L. Information technology, workplace, organization and the demand for skilled labor: A firm level analysis. *Quarterly Journal of Economics, 111,* 1 (February 2002), 339–376.

7. Brynjolfsson, E. The productivity of information technology: Review and assessment. Sloan School of Management working paper 3417–92, Cambridge, MA, 1991.

8. Brynjolfsson, E., and Hitt, L. Information technology as a factor of production: The role of differences among firms. *Economics of Innovation and New Technology, 3,* 4 (April 1995), 183–200.

9. Brynjolfsson, E., and Hitt, L. Paradox lost? Firm-level evidence on the returns to information systems. *Management Science, 42,* 4 (April 1996), 541–558.

10. Brynjolfsson, E., and Hitt, L. The customer counts. *Informationweek* (September 9, 1996), 38–43. Available at www.informationweek.com/596/96mit.htm.

11. Brynjolfsson, E., and Hitt, L. Beyond the productivity paradox. *Communications of ACM, 41,* 8 (August 1998), 49–55.

12. Brynjolfsson, E., and Hitt, L. Computing productivity: Are computers pulling their weight? Mimeo, MIT and Wharton, Cambridge, MA, 1998.

13. Brynjolfsson, E., and Hitt, L. Beyond computation: Information technology, organizational transformation and business performance. *Journal of Economic Perspectives, 14,* 4 (Fall 2000), 23–48.

14. Brynjolfsson, E., and Yang, S. The intangible costs and benefits of computer investments: Evidence from the financial markets. In K. Kumar and J.I. DeGross (eds.), *Proceedings of the International Conference on Information Systems.* New York: ACM, 1997. [Revised MIT working paper, Cambridge, MA, April 1999.]

15. Brynjolfsson, E.; Hitt, L.; and Yang, S. Intangible assets: How the interaction of computers and organizational structure affects stock market valuations. MIT Working Paper, Cambridge, MA, July 2000.

16. Cotteleer, M.; Austin, R.; and Nolan, R. Cisco Systems, Inc.: Implementing ERP. Harvard Business School case report no. 9-699-022, Boston, November 1998.

17. Davenport, T.H. Putting the enterprise into the enterprise system. *Harvard Business Review, 76,* 4 (July–August 1998), 121–131.

18. Dolmetsch, R.; Huber, T.; Fleisch, E.; and Österle, H. Accelerated SAP: 4 case studies. Institute for Information Management, University of St. Gallen, Switzerland, April 1998.

19. Doms, M.; Dunne, T.; and Troske, K. Workers, wages, and technology. *Quarterly Journal of Economics, 112,* 1 (February 1997), 253–290.

20. Escalle, C.; Cotteleer, M.; and Austin, R. Enterprise resource planning (ERP). Harvard Business School case report no. 9-699-020, Boston, November 1999.

21. Gable, G., and Vitale, M.R. (eds.). The future of enterprise resource planning systems. *Information Systems Frontiers, 2,* 2 special issue (August 2000).

22. Galbraith, J. Organization design: An information processing view. *Interfaces, 4,* 3 (May–June 1974), 28–36.

23. Gattiker, T., and Goodhue, D. Understanding the plant level costs and benefits of ERP: Will the ugly duckling always turn into a swan? In R. Sprague Jr. (ed.), *Proceedings of the Thirty-Third Annual Hawaii International Conference on System Sciences.* Los Alamitos, CA: IEEE Computer Society Press, January 2000.

24. Gibson, N.; Holland, C.; and Light, B. A case study of a fast track SAP R/3 implementation at Guilbert. *International Journal of Electronic Markets, 9,* 3 (June 1999), 190–193.

25. Hall, B.H. The manufacturing sector master file: 1959–1987. NBER working paper 3366, Cambridge, MA, May 1990.

26. Hitt, L. Information technology and firm boundaries: Evidence from panel data. *Information Systems Research, 10,* 2 (June 1999), 134–149.

27. Hitt, L., and Brynjolfsson, E. Productivity, business profitability, and consumer surplus: Three different measures of information technology value. *MIS Quarterly, 20,* 2 (Summer 1996), 121–142.

28. Kelley, M. Productivity and information technology: The elusive connection. *Management Science, 40,* 11 (November 1994), 1406–1425.

29. Martin, M. An ERP strategy. *Fortune* (February 2, 1998), 95–97.

30. McAfee, A. The impact of enterprise resource planning systems on company performance. Paper presented at Wharton Electronic Supply Chain Conference, Philadelphia, December 1999.

31. McAfee, A., and Upton, D. Vandelay industries. Harvard Business School case report no. 9-697-037, Boston, April 1996.

32. Morgan Stanley Dean Witter (MSDW). CIO survey series: Enterprise software, Releases 1.1–2.1. MSDW, New York, March 1999–March 2001.

33. Moustakis, V. Material requirements planning—MRP. Technical report, Management Systems Lab, Department of Production and Management Engineering, Technical University of Crete, January 2000.

34. Mukhopadhyay, T.; Lerch, F.; and Mangal, V. Assessing the impact of information technology on labor productivity—A field study. *Decision Support Systems, 19,* 2 (February 1997), 109–122.

35. Mukhopadhyay, T.; Rajiv, S.; and Srinivasan, K. Information technology impact on process output and quality. *Management Science, 43,* 12 (December 1997), 1645–1659.

36. O'Leary, D. *Enterprise Resource Planning Systems: Systems, Life Cycle, Electronic Commerce, and Risk.* New York: Cambridge University Press, 2000.

37. Oliner, S.D., and Sichel, D.E. Computers and output growth revisited: How big is the puzzle? *Brookings Papers on Economic Activity: Microeconomics, 2* (January 1994), 273–334.

38. Österle, H.; Feisch, E.; and Alt, R. *Business Networking: Shaping Enterprise Relationships on the Internet.* New York: Springer, 2000.

39. PriceWaterhouseCoppers. *Technology Forecast.* Palo Alto, CA: PriceWaterhouseCoppers, 1999.

40. Radosevich, L. Bankrupt drug company sues SAP. *InfoWorld* (August 27, 1998). Available at www.infoworld.com.

41. Ragowsky, A., and Somers, T. Call for papers: JMIS special section on ERP (Summer 2002), rmm-java.stern.nyu.edu/jmis/cfp/cfpERP.html.

42. Ragowsky, A.; Stern, M.; and Adams, D. Relating benefits from using IS to an organization's operational characteristics: Interpreting results from two countries. *Journal of Management Information Systems, 16,* 4 (Spring 2000), 175–194.

43. Ross, J.W. The ERP revolution: Surviving versus thriving. MIT white paper, Cambridge, MA, November 1998.

44. Sarkis, J., and Gunasekaran, A. (ed.). Enterprise resource planning—Modeling and analysis. *European Journal of Operational Research,* special issue (forthcoming 2002).

45. SAP America. SAP annual report. SAP America, Newtown Square, PA, April 1996.

46. Stemand, C. Big retail SAP project put on ice. *Computerworld* (November 2, 1998), 1, 104. Available at www.computerworld.com/cwi/story/0,1199,NAV47_STO34257,00.html.

47. Stemand, C. ERP user interfaces drive workers nuts. *Computerworld* (November 2, 1998), 1, 24. Available at www.computerworld.com/cwi/story/0,1199,NAV47_STO43325,00.html.

48. Varian, H. *Microeconomic Analysis.* Cambridge: MIT Press, 1990.

49. Westerman, G.; Cotteleer, M.; Austin, R.; and Nolan, R. Tektronix: Implementing ERP. Harvard Business School case report no. 9-699-043, Boston, February 1999.

50. White, J.; Clark, D.; and Ascarelli, S. This German software is complex, expensive and wildly popular. *Wall Street Journal,* March 17, 1997, 1.