ERP Investment: Business Impact and Productivity Measures

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ABSTRACT: Enterprise Resource Planning (ERP) software system integrates key business and management processes within and beyond a firm's boundary. While the business value of ERP implementations have been extensively debated in IT trade periodicals in the form of qualitative discussion or detailed case studies, there is little large sample statistical evidence on who adopts ERP and whether the benefits of ERP implementation exceed the costs (and risks).

With multi-year multi-firm ERP implementation and financial data, it is found that larger firms (and those with slightly better performance) tend to invest in ERP. 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: ERP systems, ROI, productivity analysis.

I. Introduction

Enterprise Resource Planning software systems (ERP) 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. The license/maintenance revenue of ERP market was $17.2 billion dollars in 1998, it is expected to be $24.3 billion dollars in 2000, and ERP systems have been implemented in over 60% of multi-national firms (PriceWaterhouseCoppers, 1999). 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 (O'Leary, 2000).

The appeal of the ERP systems is clear. While 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 standalone, custom-built systems. 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, while individual workers can have greater access to information, enabling increasing delegation of authority for production decisions as well as improved communications to customers (O'Leary, 2000).

Implementation of ERP systems requires a substantial investment in time, money and internal resources (Bailey, 1999; White, Clark and Ascarelli, 1997) and is fraught with technical and business risk (Austin and Cotteleer, 1999). A typical ERP installation has a total cost of about $15 million (O'Leary, 2000, p. 6) and costs can be as high as 2-3% of revenues (Escalle, Cotteleer, and Austin, 1999). Installation takes between 1 and 3 years (21 months on average), with benefits starting to accrue in an average of 31 months (McAfee, 1999; O'Leary, 2000). 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.[1] There is also a high degree of managerial complexity of these projects. While ERP systems are packaged software applications, the majority (~60%) of project cost is devoted to setup, installation and customization of the software, services typically provided by outside consultants such as Andersen Consulting or EDS (Dolmetsch et al., 1998; Oesterle, Fleisch and Alt, 2000).[2] 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 (Oesterle, Feisch and Alt, 2000). Numerous cases document ERP implementation failures (Davenport, 1998; Martin, 1998), some with disastrous results.[3]

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 have a significant and measurable effect on firm performance. While both costs and potential benefits are

[1] Thomas Van Weelden, CEO of Allied Waste, noted 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" (Bailey, 1999).

[2] For a typical ERP project cost breaks down as follows: Software Licensing (16%), Hardware (14%), Consulting (60%), training and other internal staff costs (10%).

[3] The SAP-Siebel-Manugistics implementation at Hershey was three months behind schedule, and Hershey officials offered this late implementation as partial explanation for why Hershey missed 10% of its expected earnings (Branch, 1999). Geneva Steel (O'Leary, 2000, pp. 39 – 48, 219) declared bankruptcy the day after their $8 million SAP system was implemented. FoxMeyer (a 7-billion-dollar 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 (Radosevich, 1998). It is estimated that at least 90% of ERP implementations end up late or over budget (Martin, 1998).

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.

To date, most of the documentation of the benefits of ERP has been in the form of individual case studies (e.g., Dolmetsch, et al., 1998; Cotteleer, Austin, and Nolan, 1998; McAfee, 1999; Gibson, Holland, and Light, 1999; Westerman et al., 1999), product testimonials (SAP Press Release) and industry surveys (AT Kearney, 1996, 1998, 2000; MSDW CIO Surveys on Enterprise Software, 1999 - 2001). In this paper, we systematically study the productivity and business performance effects of ERP using a unique dataset 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.

II. 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.

II. A. 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. While work at the economy-wide level has typically shown equivocal results until very recently (see e.g., Oliner and Sichel, 1994), research at the firm-level has demonstrated that information technology investment has a significant effect on productivity levels, productivity growth, and stock market value of firms (Brynjolfsson and Hitt, 2000).

Other research has also found some positive effects on internal performance metrics such as inventory turnover (Barua, Kriebel and Mukhopadhyay, 1995).

While much is known about the general effect of information technology on productivity, there is less understanding of the value of specific information technology 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 (Mukhopadhyay, Rajiv and Srinivasan, 1997; Mukhopadhyay, Lerch and Mangal, 1997). Benefits were also found in research of the plant level for automated machine tools (Kelley, 1994) and for "advanced manufacturing technologies", most of which are computer-related (Doms, Dunne and Troske, 1997). Brynjolfsson, Hitt and Yang (2000) 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 (1995) found that firms that invested more heavily in business process redesign and devoted more of their IT resources to increasing customer value (e.g. quality, timeliness, convenience) had greater productivity and business performance. 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.

II.B. Impact of ERP Implementation

There is a small but growing literature on the impact of ERP systems; the majority of these studies are interviews, cases studies or a collection of case studies and industry surveys (see e.g. McAfee and Upton, 1996; Davenport, 1998; Ross, 1998; AT Kearney, 1996, 1998, 2000; MSDW CIO Surveys on Enterprise Software, 1999 - 2001). McAfee (1999) studied the impact of ERP systems on self-reported company performance based on a survey of 101 US 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. Gattiker and Goodhue (2000) group the literature of ERP benefits into four categories: (1) improve information flow across sub-units, standardization and integration facilitates communication and better coordination; (2) enabling centralization of administrative activities such as account payable and payroll; (3) reduce IS maintenance costs and increase the ability to deploy new IS functionality; (4) ERP may be instrumental in moving a firm away from inefficient business processes and toward accepted best of practice processes. A model based on organizational information processing theory (Galbraith, 1974) has been developed to explain the costs and benefits of ERP impact and validated using two case studies. They argue that some successfully transformed firms (the "swans") would enjoy these ERP benefits, however, others (the "ducks") might not be able to benefit from such ERP implementation due to firm- and site-specific differences (Gattiker and Goodhue, 2000).

The above studies on the impact of ERP systems suggest that there are potentially substantial benefits for firms that successfully implemented ERP systems, though there is little in terms of broad sample statistical evidence (Ragowsky and Somers, 2000). We note here the significance of ERP impact has started to attract more attention from the academics, a few special issues of leading academic journals have been edited or forthcoming (e.g., Gable and Vitale, 2000; Sarkis and Gunasekaran, 2001).

III. Data, Methods and Hypotheses

III. A. Data

Our analysis leverages and extends existing data on information technology, productivity originally used by Brynjolfsson and Hitt (2000) for the study of IT and productivity growth.[4] We combine this database on IT and other financial measures with new data on the adoption of ERP by large firms. Throughout this study, large firms are defined as

[4] These data have been used for related work by Brynjolfsson and Yang (1998); Bresnahan, Brynjolfsson and Hitt (2000) and Brynjolfsson, Hitt and Yang (2000).

either all publicly traded firms on Compustat or the Fortune 1000. Details on each of these data sources appear below.

III. A. 1. 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 (e.g., 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. While there are over 40 modules or variations of modules in the system, they can be broadly grouped into 5 primary areas: manufacturing, finance, human resources, project management, and information systems.[5] We will utilize these groupings for some of our analyses. The data is maintained at the level of individual sites, while our other data is at the level of the firm – we therefore aggregate the data to the firm level for many of 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 US, but using this method we are able to match 70% of all firms in the database.

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

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% of the ERP market today (higher historically) at large firms (see the annual report of SAP America, 1996 and other sources[6]), 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 non-adopters, 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 several 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

[6] A presentation by SAP executives in 1996 gives the following detailed information about the user of SAP R/3 in America's Fortune 500 companies: 6 out of the top 10 American companies; 7 out of the 10 most profitable companies; 9 out of the 10 companies with the highest market value; 7 out of the top 10 pharmaceutical, computer, and petroleum companies; 6 out of the top 10 electronics companies; 8 out of the top 10 chemical and food companies. These numbers have been increased since then (Source: SAP America's annual reports, 1996 - 1998).

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 further the 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-US 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 standalone fashion.

III. A. 2. 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 (Hall, 1990) and specifically the business value of IT (Brynjolfsson and Hitt, 2000; Hitt and Brynjolfsson, 1996; Brynjolfsson and Yang, 1999). 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 Section IV for more details).

III. A. 3. IT 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 which is purchased by individuals or departments without the knowledge of information systems 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 information technology, which, while not perfect, is useful for discriminating between high and low users of IT.

III. A. 4. Descriptive Statistics

Our primary data (Compustat and ERP adoption) span the 1986-1998 time period, resulting in 24037 firm-years observations for the entire population of firms with valid data on all performance metrics and productivity data, including 4069 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 information technology data from computer intelligence, the population is reduced to 5603 firm-years with 1117 with SAP implementations.

III. B. 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 in IT and productivity (Hitt and Brynjolfsson, 1996; Brynjolfsson and Yang, 1998; Brynjolfsson, Hitt and Yang, 2000). 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.

III. B. 1. 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:

$$\log(\textit{performance ratio numerator}) = \textit{Intercept} + \log(\textit{performance ratio denominator}) + \textit{Adoption Variables} + \textit{Year Controls} + \textit{Industry Controls} + \varepsilon \quad (1)$$

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.[7] Various performance ratios are compared as they capture different aspects of firm performance, both in terms of bottom line profitability (e.g. 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)[8] to remove variation in performance ratios due to idiosyncratic characteristics of the production process of different industries.

[7] This formulation relies on the property that log(A/B) = log(A) – log(B). We thus estimate a specification that has log(A) = intercept + $a_1$log(B) + other controls. The other controls retain their interpretation as change in the performance ratio and the interpretation is identical if a_1=1.

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

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 of f(·) that relates output (in our case value-added, which is sales less 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 (see Brynjolfsson and Hitt, 1996 for a discussion of this formulation; Varian, 1990 discusses general properties of production functions). In a production function the intercept term has a special interpretation, commonly called "multifactor productivity", as the 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:

$$\log VA = Intercept + Adoption\ \ Variables + a_1 \log K + a_2 \log L$$
$$+ Year\ Controls + Industry\ \ Controls + \varepsilon \qquad (2)$$

This type of analysis captures 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, while 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 the stock market 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, 1998 and the references therein). In addition, because investor expectations can incorporate intangible benefits of IT investment which 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 (Brynjolfsson and Hitt, 2000). For our work, we adopt a simplified version of the specification of Brynjolfsson and Yang (1997; 1999) that 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:

$$\log(\textit{market value}) = \textit{Intercept} + \textit{Adoption Variables} + \log(\textit{book value}) + a_1 K_1 + a_2 K_2 + a_3 K_3 + \textit{Year Dummies} + \textit{Industry Dummies} + \textit{Error} \quad (3)$$

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

III. B. 2. 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 effect of ERP implementation to be non-negative, 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 0 if the firm is a non-adopter of ERP over our entire sample period, and 1 if the firm adopts ERP. We explore variants of these specifications by allowing this variable to represent the extent of adoption (number of modules, etc.) in addition to the general adoption decision. Note that in this formulation we can 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.

An alternative approach to gauge the value of adoption is rather than comparing the firm to the general population, 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 non-productive 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 2 years or more after the implementation has started. In addition, Austin and Cotteleer (1999) 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:

H2-1: There is a drop in performance during ERP implementation as measured using performance ratios and productivity regressions.

H2-2: 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[9]. 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:

H3-1: There is an increase in stock market valuation at the initiation of an ERP implementation.

H3-2: 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 1 at the year of first ERP implementation and remains 1 afterwards. It is 0 prior to any implementation.

End_Impl: is 1 at the year when first ERP implementation is finished and remains as 1 afterwards. It is 0 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 non-adopters to gain a greater contrast between firms in different stages of implementation and non-adopters.

III. B. 3. Empirical Methods: Economies of Scope and Scale in ERP Adoption

It is believed that different functional modules of ERP package will work out in harmony if all implemented. 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

[9] An example would be the follow-up story of SAP-Siebel-Manugistics implementation at Hershey, as footnoted previously, where benefits have been regained in the long-run. Private communication with a

level 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 information systems).

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 (e.g., Moustakis 2000), is not readily applicable for this analysis since we have both manufacturing and service firms (which typically do not have manufacturing or inventory management issues). In addition, according to the APICS ABCD classification for MRP systems, all the manufacturing firms (except one firm who only implemented the inventory management module) on our sample would be at the same level (i.e., Class A) since they implemented ERP[10]. As a result, we chose to develop a classification system based on the actual patterns of usage of the various SAP modules. An analysis of patterns of implementation in these data shows that the vast majority of firms (>90%) implement one of four common module combinations which we will label as different implementation *Levels*. We describe a firm that has implemented any single module or an unusual combination of two modules as Level 0 – this applies to less than 10% of the firms. Firms that implement the core manufacturing, finance and IS modules are Level 1. Those that have Level 1 functionality that also implement project management are Level 2A and those that have Level 1 functionality that 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:

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team member of the Hershey project.

[10] 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, include 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 lease degree of implementation where MRP is used for tracking data only. For more details, see, e.g., Moustakis (2000), pp. 7, or visit www.apics.org. We thank a referee for directing

H4-1: 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:

H4-2: At some level of implementation the benefits of increased module integration may decline (as coordination costs or other diseconomies set in).

IV. Results and Interpretation

In this section we report results on our analyses comparing adopters to non-adopters on a variety of performance metrics, comparing firm performance before, during and after adoption, and then modeling the adoption decision.

IV. A. Comparison between Adopters and Non-Adopters

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 1 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

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our attention to this, which results the classification and grouping of ERP implementation data for

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% (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 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 1.7% and 4.2% 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% and 1.7% when we include controls for computer usage (replicating the specifications used by Brynjolfsson and Hitt, 1996; 2000) – 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 information technology. 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.

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subsequent analyses.

Results of a simple Tobin's q model (Table 4 columns 3 and 6) echo the previous results as well. Our results suggest that firms that implemented ERP are worth approximately 13% more than their non-adopting counterparts, controlling for assets, 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% ($t=5.00$, $p<.001$). We therefore focus on the market value regressions controlling for IT capital use to be more conservative.

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

IV. B. 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, while the "during adoption" estimates are probably closer to the average performance over the implementation period.

Our results on performance analyses using the same specifications previously (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 pre-existing 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 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 an annual performance benefit for the 1.5 years of an average implementation.

Similar results are found in the productivity regressions (Table 6 columns 1, 2, 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% during implementation with a loss of 4.7% for a net gain of –1.1% (t=.8, not significant). Results are somewhat stronger in the productivity specification with output as the dependent variable – gains of 2.4% offset by a smaller loss of 1.7%. 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 3 and 6) are consistent with adjustment rather than productivity decline as the explanation. During the implementation period, the firm receives an additional 6.3% (t=1.75, p<.1) percent market valuation. This further increases at the end of implementation by 1.6% (t=.4, n.s.). Although this change is not significant, there is a substantial change from pre- to post-implementation (7.9%, t=2.2, p<.01). This is consistent with Hypothesis 3-1 and 3-2 (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% of total value) relative to their long run value at completion. This is what would be expected if markets believed that there was substantial, but not overwhelming, risk of ERP projects.[11]

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 rewarding not 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 Brynjolfsson, Hitt and Yang, 2000 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.

IV. D. 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. 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 non adopters), although the general patterns are virtually identical if you restrict the sample to ERP adopters only and compare the different levels. The

[11] For example, if an ERP project were highly risky in the sense that it provided a +2% productivity gain with 50% probability and a –2% loss with 50% probability, the market should not reward the project until after successful completion. If the numbers were +5% and +3% for success and failure respectively, a 4% gain might appear upon announcement, with the remaining amount (on the order of a 1%) 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).

baseline in the sample is non-adoption, 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 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 HR module adding more value than the project management module (these differences are all significant at $p<.01$). 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, even though it adds value on its own (the difference between Level 1 and Level 2A).

V. Conclusion and Future Directions

Empirical data results have provided general support for our hypotheses. We find that ERP adopters are consistently higher in performance across a wide variety of measures than non-adopters. 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 rewards 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. While 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) or the long-term impact on productivity (due to lack of long-term post implementation data at this time), both of these issues are promising areas for future research.

VI. Acknowledgement

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Table 1: Data Construction of Financial Performance Measures

Ratio	Definition	Interpretation
Labor Productivity	Sales/# of Employees	*Profitability Measure:* High ratio indicates more productive 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/CI Population
Total Observations	24037	5069
Observations of ERP Adopters	4069	1117

Table 3: Performance Ratio Regressions (Pooling Adopters and Non-Adopters)

Dependent Variable	ln(Sales)	ln(Pretax Income)	ln(cost of goods sold)	ln(pretax income)	ln(pretax income)	ln(Sales)	ln(Sales)	ln(Debt)
Column	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Interpretation	Labor Prod.	ROA	Inventory Turnover	ROE	Profit Margin	Asset Utilization	Collection Efficiency	Leverage
Implementation (1=implemented)	0.267*** (0.0145)	0.133*** (0.0195)	0.0777*** (0.0192)	-.0628*** (0.0164)	.0984*** (0.0206)	0.123*** (0.0122)	0.1955*** (0.0175)	-.0796** (0.0235)
ln(Employees)	0.891*** (0.0035)							
ln(Assets)		0.928*** (0.00442)				0.863*** (0.00270)		
ln(Inventory)			0.728*** (0.00394)					
ln(Equity)				0.938*** (0.00346)				0.852*** (0.00495)
ln(Sales)					0.971*** (0.00488)			
ln(Accounts Rcv)							0.718*** (0.00351)	
Control Variables	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year
R^2	0.825	0.769	0.712	0.8407	0.744	0.8779	0.7514	0.725
Observations	24037	24037	24037	24037	24037	24037	24037	24037

*** - p<.001;** -p<.01; * - p<.05

Table 4: Productivity and Market Value Regressions (Pooling Adopters and Non-Adopters)

Dependent Variable	ln(Value Added)	ln(Output)	ln(Value Added)	ln(Output)	ln(Market Value)	ln(Market Value)
Column	(1)	(2)	(3)	(4)	(5)	(6)
Implementation (1=implemented)	0.042*** (0.00638)	0.023*** (0.00400)	0.0273** (0.00786)	0.0174** (0.005)	0.128*** (0.00829)	0.026*** (0.0052)
ln(Computer Capital)			0.0249 *** (0.00328)	0.009*** (0.002)		0.0387*** (0.0042)
ln(Ordinary Capital)	0.34*** (0.00271)	0.182*** (0.00221)	0.306*** (0.00468)	0.133*** (0.00373)		
ln(Labor Expense)	0.647*** (0.00283)	0.29*** (0.00188)	0.659*** (0.00474)	0.258*** (0.00317)		
ln(Materials)		0.514*** (0.00198)		0.586*** (0.00355)		
ln(Total Assets)					0.9824*** (0.00173)	0.953*** (0.00517)
Control Variables	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year
R^2	24037	24037	5603	5603	24037	5603
Observations	0.9613	0.9849	0.9631	0.9847	0.9521	0.9414

*** - p<.001;** -p<.01; * - p<.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)
Column	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Interpretation	Labor Prod.	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*** (.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 Rcv)							0.928*** (0.00551)	
Control Variables	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year
R^2	0.9055	0.823	0.8617	0.8765	0.8207	0.9564	0.9245	0.7663
Observations	4069	4069	4069	4069	4069	4069	4069	4069

*** - p<.001;** -p<.01; * - p<.05

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)
Column	(1)	(2)	(3)	(4)	(5)	(6)
Implementation Started (1/0)	0.036 (0.0241)	0.024 (0.0168)	0.021 (0.0250)	0.025 (0.0132)	0.0630 (0.0360)	0.112* (0.0476)
Implementation Completed (1/0)	-0.047 (0.0246)	-0.017 (0.0171)	-0.069* (0.0289)	-0.029* (0.0153)	0.0161 (0.0364)	0.0927 (0.0552)
ln(Computer Capital)			0.0315 *** (.00668)	0.0111*** (0.00355)		0.036*** (0.0111)
ln(Ordinary Capital)	0.368*** (0.00821)	0.111*** (0.00812)	0.326*** (0.01)	0.0947*** (0.00762)		
ln(Labor Expense)	0.635*** (0.00869)	0.281*** (0.00622)	0.645*** (0.011)	0.241*** (0.00575)		
ln(Materials)		0.612*** (0.00720)		0.656*** (0.0067)		
ln(Total Assets)					0.9805*** (0.00445)	0.9613*** (0.0118)
Control Variables	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year
R^2	0.9715	0.9868	0.9740	0.9921	0.9479	0.9317

*** - p<.001;** -p<.01; * - p<.05

Table 7: Productivity Effect of Different Levels of Adoption

Dependent Variable	ln(Value Added)	ln(Output)	ln(Market Value)
Column	(1)	(2)	(3)
Non Adopter	0	0	0
Any Module (Level 0)	0.0900*** (0.0207)	0.0384** (0.0129)	0.0436*** (0.0115)
Manufacturing & Finance (Level 1)	-0.00231 (0.0108)	0.00195 (0.00678)	0.0329*** (0.00601)
Man., Fin. and Project Mgmt. (Level 2A)	0.0358*** (0.0109)	0.0248*** (0.00679)	0.0689*** (0.00621)
Man., Fin. and HR (Level 2B)	0.0816*** (0.0203)	0.0908*** (0.0127)	0.0917*** (0.0119)
All (Level 3)	0.0746*** (0.0113)	0.0206** (0.00710)	0.0539*** (0.00648)
ln(Ordinary Capital)	0.339*** (0.00271)	0.182*** (0.00221)	
ln(Labor Expense)	0.647*** (0.00647)	0.290*** (0.00188)	
ln(Materials)		0.514*** (0.00198)	
ln(Total Assets)			0.982*** (0.00174)
Control Variables	Industry Year	Industry Year	Industry Year
R^2	0.961	0.985	0.952
Sample	Full (including non adopters)	Full (including non adopters)	Full (including non adopters)

*** - p<.001;** -p<.01; * - p<.05

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