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WHICH CAME FIRST, IT OR PRODUCTIVITY?

A VIRTUOUS CYCLE OF INVESTMENT AND USE IN ENTERPRISE SYSTEMS

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Abstract

While a number of studies have found that IT intensive firms are more productive, a critical question remains: Does IT cause productivity or are productive firms simply willing to spend more on IT? We address this question by examining the productivity and performance effects of enterprise systems investments in a sample of 698 large public U.S. firms over eight years. The data represent the entire universe of U.S. customers of a large vendor from 1998 to 2005 and include the vendor's three main suites of enterprise systems: Enterprise Resource Planning (ERP), Supply Chain Management (SCM), and Customer Relationship Management (CRM). A particular benefit of our data is that it distinguishes the purchase of enterprise systems from their installation and use. Because enterprise systems often take years to implement, the performance of firms at the time of purchase is often quite different from their performance after the systems "go-live." In our ERP data, we find that purchase events are uncorrelated with performance while go-live events are positively correlated. This indicates that the use of ERP systems actually causes performance gains rather than strong performance predicting the purchase of ERP. In our SCM and CRM data, performance is correlated with both purchase and go-live events. Because SCM and CRM can only be installed after ERP, these results imply that those firms that experience performance gains from ERP adoption go on to purchase SCM and CRM. Our results are robust to several alternative explanations and specifications and together suggest that a causal relationship between ERP and performance triggers additional IT adoption in firms that derive value from the initial investment. These results provide an explanation of simultaneity in IT value research that fits with rational economic theory: As firms that successfully implement IT (and complementary intangible investments) see greater marginal benefits to additional IT investments, they react by investing in more IT. Our work suggests replacing "either-or" views of causality with a positive feedback loop conceptualization in which successful IT investments initiate a "virtuous cycle" of additional investment and additional gain. Our work also reveals other important estimation issues that can help researchers identify relationships between IT and business value in future research.

Keywords: Business Value of Information Technology, Productivity, Simultaneity, Causality, Software Investment, Production Function, Enterprise Resource Planning, Supply Chain Management, Customer Relationship Management, Process Enabling IT, Selection Effect.

1. Introduction

Do IT investments cause increases in firm productivity and performance? While IT may be correlated with increased productivity, determining the causal direction of the relationship is essential to understanding whether IT actually pays off or whether investment in IT is simply a by-product of success which has other root causes. A definitive answer to this question has defied purely 'econometric' solutions, such as instrumental variables, because good instruments generally do not exist. Case studies, which outline how firms change and improve their performance in concert with IT investments, are useful but difficult to generalize. Indeed, just as productivity proponents can cite IT success stories, skeptics can site cases of reverse causality, where IT investments seem to be enabled by excess cash flow.

The ideal empirical solution to this puzzle would separate estimation of the relationship between IT investment and performance from estimation of the relationship between IT use and performance. Furthermore would observe these events one or more years apart in the same firms. By empirically distinguishing investment from use, researchers could disentangle the complex relationship between IT and firm performance. In this paper, we take advantage of a unique data set that actually meets these stringent criteria.

We examine IT business value in the context of "enterprise systems" – company wide suites of business software devoted to particular processes integrated across the value chain: Enterprise Resource Planning (ERP), Supply Chain Management (SCM), and Customer Relationship Management (CRM). We collected enterprise systems adoption data on all U.S. customers from 1998 to 2005 from the sales database of one large enterprise systems vendor and tested the productivity and performance implications of purchasing and going-live with the vendor's three main system suites – ERP, SCM, and CRM. The data contain distinct entries for purchase and go-live events separately, enabling us to disentangle estimates of 'investment' from estimates of 'use.' The finer granularity of our data allows us to directly address the question of causality in our estimates.

Our research has three primary goals: (1) to pursue independent estimation of purchase and go-live decisions to shed light on the casual direction of relationships between enterprise systems and productivity and performance; (2) to provide up to date large sample statistical evidence of the productivity and performance implications of enterprise systems; and (3) to explore the differential productivity and performance implications of IT adoption in processes inside and outside the firm boundary.

Our results provide empirical evidence of a causal relationship between enterprise systems adoption and firm performance. In our ERP data, we find that purchase events are uncorrelated with performance while go-live events are positively correlated. This implies that the use of ERP systems actually causes performance gains rather than strong performance leading to the purchase of ERP. In our examination of the purchase and go live events of SCM and CRM, performance is correlated with both purchase and with go-live. These results imply that firms experiencing performance gains from ERP adoption go on to purchase SCM and CRM. Our results are robust to several alternative explanations and specifications and together suggest a causal relationship between ERP and performance, which in turn triggers additional IT adoption in firms that derive value from the initial investment. These results provide an explanation of simultaneity in IT value research that fits with rational economic theory: As firms that successfully implement IT (and complementary intangible investments) see greater marginal benefits to additional IT investments, they react by investing in more IT. We suggest replacing "either-or" views of causality with a more specific 'positive feedback loop' conceptualization in which successful IT investments initiate a "virtuous cycle" of additional investment and additional gain. Thus our data and analysis bring together both the productivity proponents and skeptics in a unified framework.

Interestingly, we also find that external SCM and CRM systems have a significantly larger impact on productivity and performance than internal ERP systems, and that since 1998, SCM and CRM explain some of the performance gains originally attributed to ERP. While there are several possible explanations for this result, the evidence is strongest for a 'selection effect' whereby firms who succeed with ERP go on to adopt SCM and CRM, while those who fail do not. Finally we show that the lagged benefits to ERP implementation cannot explain the strong relationship between SCM and CRM adoption and performance in longitudinal analyses. Together, these results provide evidence of a causal relationship between enterprise systems and firm performance and demonstrate the importance of estimating the returns to systems of process enabling IT simultaneously.

2. Theory & Literature

2.1 Addressing Simultaneity Bias in Estimates of the Returns to IT

One of the most vexing problems in estimating the productivity or performance impacts of IT is simultaneity bias – errors introduced into estimations of variables simultaneously determined by the same forces (Griliches & Mairesse 1995). If differences in firm performance are known to firms when they choose inputs, then simple estimation procedures can upwardly bias estimates of input coefficients (Olley & Pakes 1996). For example, firms with windfall profits due to causes other than IT might choose to invest that profit in new IT capital. Standard regressions models may wrongly attribute part of that performance difference to the investment itself. In this way, simultaneity not only creates difficulties in determining the causal direction of relationships between factor inputs and output, it can create incorrect estimates of the relationships themselves.

Several possible sources of simultaneity exist in the relationship between IT and firm performance. If positive shocks to productivity or output occur at particular times during the observation period, these shocks may simultaneously effect investments in IT and the productivity and performance of firms. Shocks could also be industry or firm specific. If firms undertake large technology implementations when demand for their products is high or when they *expect* to perform well, estimates of the impact of IT adoption on output may be biased upward (Brynjolfsson & Hitt 2003). The decision to adopt enterprise systems could be correlated with performance for several reasons. A windfall could trigger expenditures designed to take a firm ‘to the next level.’ Frequently, positive performance gains are used to make new technology investments that build competitive barriers. In addition, managers expecting an up tick in demand for their products may invest in ERP. Ramping up of production frequently requires coordinated production planning activities which are the primary function of ERP systems.

Several econometric techniques have been used previously to attempt to correct coefficient estimates and to enable tractable causal interpretations. The classic approach involves the collection of data on instrumental variables that are correlated with IT purchases but contemporaneously uncorrelated with performance. Researchers have used data on client server architectures (Brynjolfsson & Hitt 1996), age of capital stock (Gao & Hitt 2004), and capital constraints (Brynjolfsson & Hitt 2003) (among other things) to address simultaneity. In the case of panel data, various formulations of lagged values of dependent variables (Arellano & Bond 1991) have been used as instruments. Finally, estimates of difference equations, simultaneous equations or seemingly unrelated regressions (SUR) have been used in conjunction with instrumental variable methods to improve parameter estimates (Brynjolfsson & Hitt 1996).

These methods provide important advances in our ability to estimate the impact of IT on productivity and performance. However, a good instrument is hard to find. Acquiring reliable data on variables strongly correlated with IT but uncorrelated with performance is not easy. Any correlation with performance disrupts the ability to correct for simultaneity and instruments that are only weakly correlated with IT make it difficult to estimate its true impact. Instruments based on lagged values of the dependent variable typically have low power creating wide confidence intervals that make it difficult to precisely estimate the impact of IT, and may be contaminated by serial correlation (Brynjolfsson & Hitt 2003).

In this paper we follow a fundamentally different empirical estimation approach. Instead of employing instrumental variable techniques, we estimate IT purchases and IT use separately. By empirically separating the *purchase* of IT from *implementation* and *go-live* events we distinguish firms' decisions to invest in new technology from the impact of using the technology in their daily businesses. If firm performance is correlated with implementation and use, but uncorrelated with purchase then we can reasonably assume that the relationship with performance is not being driven (at least primarily) by the simultaneous determination of investment and performance. This type of analysis is not possible with aggregate measures of IT investment, which are too coarse to disentangle the investment decision from the use of the technology. Nor is it possible with 'single instance' adoption data that do not distinguish purchase or investment events from technology use. Our approach is loosely based on the work of Olley and Pakes (1996), who conceive of an econometric procedure that explicitly models firms' investment decisions as a function of their productivity. In our case, we collect data on and estimate purchase events separately from the implementation and the use of IT.

2.2. Measuring Discrete IT Adoption Events

Most studies measure IT adoption as a single discrete event. However, the adoption of large-scale enterprise systems typically span several years punctuated by discrete observable events including the decision to adopt an enterprise suite, the date of purchase and the go-live date. For example, in our interviews at Scientific-Atlanta, a large global electronics and telecommunication equipment manufacturer, management decided to purchase an ERP system in 1992 when the CEO came on board, purchased the system in December 1994, started implementation in July 1995, and went live with phase one in April 1996 and with the fully integrated system in January 1997. The success of their ERP implementation led them to future implementations of SCM/CRM systems (e.g. supply chain procurement using reverse auctions) in 2004-2005. Figure 1 illustrates a typical timeline for the adoption of ERP, SCM and CRM. Note especially the time distinction of each discrete (sequential) adoption event within each suite. Figure 1 depicts the specific dates of Scientific Atlanta's timeline. The adoption events across suites may overlap in time.

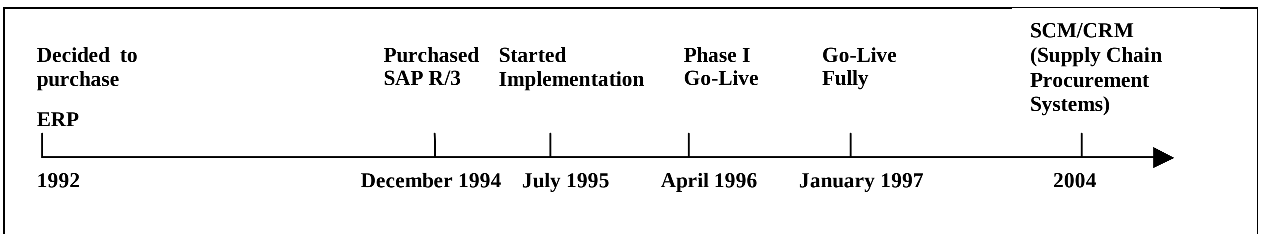

Figure 1. Scientific-Atlanta ERP Timeline

In our data we observe the exact dates of purchase and go-live events of 698 firms over eight years. This enables us to examine separately the relationship between performance and purchase vs. performance and go-live. We can thus untangle the causal direction of the relationship between IT adoption and performance. If higher performance inspires IT adoption we would expect to see performance associated with the decision to purchase a given system. If however IT adoption drives performance, we would expect to see no relationship between performance and *purchase* events and a positive relationship between performance and *go-live* events.[1]

2.3. The Evolution of Enterprise Systems and Extensions Beyond the Firm

Since the early 1970s, enterprise systems have evolved from Material Requirements Planning (MRP) and Manufacturing Resource Planning (MRPII) systems in the 1980s, to the more well known ERP systems of the 1990s, which utilize a single source of data that integrates enterprise functions such as sales and distribution, materials management, production planning financial accounting, cost control, and human resource management. In the last decade, ERP vendors began adding new suites such as supply chain management (SCM) and customer relationship management (CRM) that can be fully integrated with ERP systems. Such "extended enterprise systems" expanded the scope of enterprise software beyond the firm boundary to their suppliers, partners and customers. Since then we have seen a substantial increase in the adoption of enterprise systems. The ERP market grew 14% in 2004 and now accounts for approximately $25 billion, while the implementation of systems dedicated to external processes, such as SCM and CRM are also growing, accounting for nearly $6 billion and $9 billion respectively.[2] By 2002 over 75% of global Fortune 1000 firms had implemented SAP's ERP suite.

Although firms are relying more and more on enterprise systems to integrate processes, transactions and data, we know relatively little about the business value and productivity effects of these

[1] In fact, since purchase events are slightly lagged proxies for the 'decision to purchase,' the lack of a relationship between purchase and performance is a conservative and even more robust refutation of the reverse causality argument..

process enabling technologies. Few exceptions in the literature examine either specific (rather general purpose) technologies or isolated individual business processes (e.g. Barua et al. 1995; Ichniowski et al.1997; Mukhopadhyay et al. 1997; McAfee 2002).. Recent reviews of the IT value literature advocate investigations of the performance implications of software investments (Melville et al. 2005), the differential returns to internal and external IT investments (Bharadwaj et al. 1999) and the impact of systems of process enabling IT. Furthermore, these general purpose process enabling information technologies are catalysts for an order of magnitude larger investments in organizational capital (Brynjolfsson et al. 2005) and by some estimates, account for over half of all IT related investment (McAfee 2003). If IT matters for business performance, it should matter here.

2.4. Enterprise Resource Planning (ERP)

Although enterprise systems make up a significant and growing share of the IT investments of most large and medium sized firms, there is currently little empirical research into the performance implications of these investments. Previous evidence on ERP systems has come from qualitative case studies (e.g. Markus et al. 2000) or surveys of self reported perceptual performance (e.g. Swanson and Wang 2003), and there are relatively few studies that collect data on a large number of firms or utilize objective measures of productivity and performance. McAfee (2002) studies the impact of ERP adoption on lead time and on-time delivery in a single high tech manufacturer and finds a "performance dip" immediately after adoption followed by significant improvements in performance after several months. Swanson and Wang (2003) survey 118 ERP adopters during the mid-to-late 1990s. They identify business coordination (adoption know-why) and management understanding (implementation know-how) as critical success factors. This suggests that successful ERP adopters gain important knowledge advantages over less successful or failed ERP adopters for the next stage of enterprise IT innovations such as SCM and CRM. Hendricks et al. (forthcoming) study the impact of ERP, SCM and CRM adoption

[2] AMR "Market Analytix Report: Enterprise Resource Planning 2004-2009" referenced in Network World, 06/15/05.

announcements. They find SCM adopters experience positive returns in stock price performance, return-on-assets (ROA), and return-on-sales (ROS); no evidence of CRM returns in any measure; and some evidence of ERP returns in ROA and ROS, but not in market value. The study by Hitt et al. (2002) has been the largest published statistical analysis of the performance implications of ERP adoption. They study 350 publicly traded US firms between 1986 and 1998, and find that ERP adopters experience positive performance, productivity, and market value returns compared to non-adopters although their data do not allow them to test whether ERP causes such performance gains.

Most previous studies of ERP impact examine data prior to 1999, leaving a gap of an up-to-date understanding of the impacts of these nearly ubiquitous systems[3]. Up-to-date estimates are critical because recent ERP adoption is commonly accompanied by adoption of other types of process enabling IT such as SCM and CRM. If these other systems are correlated with ERP adoption and positively associated with performance, the few estimates we do have of the relationship between ERP and performance could be biased upward. To understand how the market has changed since 1999, we analyzed qualitative case evidence in two stages prior to our econometric analysis. First, we reviewed over 70 self-reported multi-industry cases that documented clients' stories in implementing ERP, SCM, or CRM. Second, we conducted our own independent case studies of two high tech companies who have implemented enterprise systems.[4] Based on our qualitative case evidence and the prior literature on ERP adoption we hypothesize:

> H1: *Firms that adopt ERP systems will have greater productivity and performance than those that do not.*

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[3] 98% of 406 announcements in Hendricks et al. (forthcoming) occurred during 1995-1999.

[4] This process led to three broad findings: (1) Business value from enterprise software derives from a series of performance enhancements at the initial and intermediate levels. Measuring and managing these intermediate performance results are critical to understand how implementation impacts business; (2) Successful enterprise software implementations are accompanied by critical intangible investments and business process changes; and (3) Firms that implement enterprise software successfully tailor their adoption decisions, implementation plans and process changes to their business strategies.

2.5. Supply Chain Management (SCM)

SCM systems not only support operational performance in terms of internal efficiencies and cost reduction (e.g. Cachon & Fisher 2000), they enable firms to serve their customers in a timely and comprehensive manner. When a supply chain experiences 'glitches,' firms experience reductions in asset utilization, operational performance and profitability (Hendricks & Singhal 2005). Effective supply chain management can improve productivity and performance through two main complementary mechanisms established in the theoretical literature: *market mediation* and *materials management* (Fisher 1997).

Market mediation involves better matching supply to demand. Effective market mediation requires accurate and timely information about the dynamics of supply and demand and incorporates several IT-enabled processes including collaborative planning and forecasting replenishment, advanced supply chain planning, and logistics and distribution management. Information sharing and collaborative forecasting can mitigate the impact of demand variability on operations and reduce the upstream escalation of order variance, or the bullwhip effect (Lee et al. 1997). Improvements to demand forecasts enable firms to increase sales and order fulfillment rates and reduce inventory costs.

Materials management involves optimizing the movement of raw materials, work-in-process (WIP) and finished goods inventories (FGI) through the supply chain. Efficiencies in the materials management process drive costs out of production, transportation and inventory storage, and SCM systems enable more effective materials management. Information sharing, collaborative planning and forecasting replenishment, and supply chain optimization can improve order quantity decisions, lower the time and costs of order processing, increase order frequencies, reduce lead times and batch sizes, reduce inventory levels and increase order fulfillment (e.g. Cachon & Fisher 2000). These operational improvements can help reduce costs, avoid lost sales, improve customer satisfaction and retention, and increase the performance of each individual firm in the supply chain. We therefore hypothesize:

> H2: *Firms that adopt SCM systems will have greater productivity and performance than those that do not.*

2.6. Customer Relationship Management (CRM)

Competitive advantage and long run business value are becoming more dependent on deep knowledge of and relationships with customers. Understanding the idiosyncrasies of heterogeneous customer preferences, valuations and consumption behaviors and determining the lifetime value of customer assets can improve marketing decisions and the return on marketing expenditures (e.g. Hogan et al. 2002). While the impacts of customer satisfaction, customer knowledge and resultant marketing actions on firm performance have been well examined (e.g. Andersen & Sullivan 1993; Hogan et al. 2002), the few studies that examine relationships between IT, customer satisfaction and firm performance (e.g. Mithas & Krishnan 2004; Mithas et al. 2005) typically focus on intermediate indicators such as customer satisfaction rather than on bottom line firm performance impacts.

CRM systems can enable effective sales force automation, centralized customer data warehousing and data mining, and decision support designed to inform marketing resource allocation decisions, promotion policies, and marketing campaigns to maximize customer satisfaction and retention. CRM may reduce costs by streamlining repetitive transactions and sales processes, and maximize data integrity by creating a central, firm wide repository of customer information. Sales automation and centralized data enable data mining to identify dynamic changes in demand, cross selling opportunities and improvements and after sales service support to customers (Cohen et al. 2006). We therefore hypothesize:

H3: *Firms that adopt CRM systems will have greater productivity and performance than those that do not.*

2.7. Theoretical Implications of IT Adoption in Processes Beyond the Firm Boundary

Despite research calls for examinations of the performance differences associated with IT adoption within and across firm boundaries (Bharadwaj et al. 1999; Melville et al. 2005), little large-sample empirical evidence exists. While both internal and external enterprise systems are expected to contribute to productivity and performance, there are theoretical reasons why external systems may have special implications for organizational structure, productivity and performance.

The boundary of the firm has long been a theoretical demarcation across which investment incentives, coordination costs, and the distribution of information are theorized to change dramatically. These differences have economic implications for the structure of contracts, the organizational decision makings (such as make vs. buy intermediate inputs), and the existence of firms (Holmstrom & Roberts 1998). Several theoretical arguments predict differential returns to IT within and across firm boundaries. There may be greater opportunities to reduce coordination costs between firms than within firms because of additional transaction costs associated with economic activities outside the firm (Coase 1937; Clemons et al. 1993). In addition, because market procurement is more coordination intensive than internal production, the efficiency gains from automating or digitizing external transactions are potentially larger than IT enabled process improvements within the firm. Finally, greater agency costs and potential opportunism that could be addressed by the improved monitoring and transparency provided by IT may exist across firm boundaries (e.g. Jensen & Meckling 1976).

At the same time, working across firms boundaries requires greater management coordination and entails greater risks than working inside the firm. The firms which overcome these barriers should be expected to earn greater returns, on average. Thus, prior theoretical and empirical work suggests the following hypothesis:

> H4: *The performance impact of adopting enterprise systems outside the boundary of the firm (e.g. SCM and CRM) will be greater than that of adopting internal ERP systems.*

3. Empirical Methods

3.1. Data

We collected detailed data on the enterprise systems purchase and go-live decisions of 2428 U.S. establishments from 1998 to 2005. The data include all U.S. sales of a major vendor's 150 software modules sold during the study period and are collected directly from the vendor's sales database. As they include distinct dates for purchase and go-live events, we measure both technology investment and use (Devaraj & Kohli 2003). Based on interviews with the vendor's sales and technical staff, we grouped modules into clusters representing major packaged software offerings including the core ERP, SCM and CRM. These groupings were validated by the vendor's representatives and we verified them using a factor analysis of firms' patterns of adoption. Our module groups clustered cleanly, indicating that the groupings represent different software suites adopted by firms. The 2428 establishments represent 725 firms, 698 of which were publicly traded and had matched performance data in the Compustat database. After removing private firms and those with missing data, we were left with an annual, balanced panel of 698 firms over 8 years.

Table 1: Descriptive Statistics

Variable	Obs.	Mean	SD	Min	Max
Sales	4328	8466.18	20555.44	0	263989
Employees	4155	28.87	67.23	.002	905.766
Capital (PPE Net)	4313	3278.368	9269.58	0	111921
Total Assets	4334	12606.96	39568.93	.07	798660
Debt	4330	1128.73	5712.48	0	93105
Total Inventories	4308	760.81	2308.09	0	58014
COGS	4328	5773.99	15503.58	0	263989
Equity	4334	3382.42	8699.79	-22295	156293
Pretax Income	4327	385.325	1754.82	-44574	25330
Accounts Receivable	4327	2651.62	13931.19	0	283824

Table 2: Correlations Among Performance Variables

		1	2	3	4	5	6	7	8	9	10
1	Sales	1.00									
2	Employees	0.72	1.00								
3	Capital (PPE Net)	0.80	0.56	1.00							
4	Total Assets	0.73	0.52	0.66	1.00						
5	Debt	0.67	0.48	0.55	0.86	1.00					
6	Total Inventories	0.68	0.55	0.48	0.65	0.59	1.00				
7	COGS	0.97	0.67	0.76	0.68	0.66	0.63	1.00			
8	Equity	0.72	0.49	0.73	0.71	0.46	0.50	0.64	1.00		
9	Pretax Income	0.49	0.32	0.44	0.41	0.31	0.33	0.43	0.51	1.00	
10	Receivables	0.57	0.40	0.40	0.82	0.84	0.69	0.55	0.41	0.29	1.00

3.2. Statistical Specifications

Following the literature on IT, productivity and business value (e.g. Brynjolfsson & Hitt 1996, 2000), we employed two main empirical specifications and a third used to check the robustness of our interpretations. We began by closely replicating the specifications used by Hitt et al. (2002) (hereafter referred to as HWZ) to maintain the comparability of our results with their previous work. We tested the relationship between enterprise systems adoption and various measures of financial performance using the following general estimating equation:

$$\begin{aligned}&\log(PerformanceNumerator)_{it} = \alpha_{it} + \beta_1 \log(PerformanceDenom.)_{it} + \beta_2 Adoption_{it} \\ &+ \sum YearControls_{it} + \sum IndustryControls_{it} + \varepsilon_{it}\end{aligned} \quad [1]$$

In line with insights gained from our qualitative case studies, the estimation uses ratios that measure labor productivity, bottom line profitability (ROA) and intermediate operational measures (e.g. inventory turnover, collection efficiency).[5] We controlled for transitory shocks to performance by including a dummy variable for each year and industry controls for 10 industry groupings at the 1½ digit SIC level. We then tested the productivity effects of enterprise systems adoption using a traditional Cobb-Douglas specification, shown in its general form in equation 2:

$$\begin{aligned}&\log(VA)_{it} = \alpha_{it} + \beta_1 \log K_{it} + \beta_2 \log L_{it} + \beta_3 Adoption_{it} + \\ &\sum YearControls_{it} + \sum IndustryControls_{it} + \varepsilon_{it}\end{aligned} \quad [2]$$

Finally, in order to verify our causal interpretations, we estimated a logistic regression of the probability of purchasing ERP, SCM and CRM as a function of performance:[6]

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[5] We estimate the numerator of the performance ratio as the dependent variable and the denominator as a control variable on the right hand side: $\log(A) = \alpha + \beta_1\log(B)$ + controls. This specification is based on the property that $\log(A/B) = \log(A) - \log(B)$. Putting the denominator on the right hand side allows us to estimate coefficients that may differ from unity.

[6] Where βX represents performance.

$$\ln\left(\frac{P(Y_i = 1)}{1 - P(Y_i = 1)}\right) = \alpha + \sum \beta \ X \ + \varepsilon \quad [3]$$

Table 3. Definitions and Interpretations of Performance Measures			
Measure (Ratio)		Definition	Interpretation
(1)	Labor Productivity	Sales/# of Employees	High ratio indicates higher labor productivity
(2)	Return on Assets	Pretax Income/Assets	High ratio indicates efficient operation of firm without regard to its financial structure
(3)	Inventory Turnover	COGS/ Inventory	High ratio indicates more efficient inventory management
(4)	Return on Equity	Pretax Income/Equity	High ratio indicates higher returns accruing to the common shareholders
(5)	Profit Margin	Pretax Income/Sales	High ratio indicates high profit generated by sales
(6)	Asset Utilization	Sales/Assets	High ratio indicates high level of sales generated by total assets
(7)	Collection Efficiency	Sales/Account Receivable	High ratio indicates effective management of customer payment
(8)	Leverage	Debt/Equity	The higher the ratio, the more leveraged the firm

4. Results

4.1. Returns to ERP

Our first task was to replicate the HWZ results, which examined the business value and productivity effects of ERP adoption from 1986-1998. Our dataset differs from HWZ in two main ways beyond its relative recency. First, in order to remain conservative in our estimates and to acknowledge the widespread adoption of ERP systems over the last eight years, we do not pool our data with Compustat data on firms not in the sales database as a proxy for “non-adopters.” Second, our data include more details about purchase and go-live decisions (the previous study only had implementation start and end dates, not “purchase,” making causal analyses difficult). While our data are more recent, more detailed, and do not include non-adopters, we are able to replicate the HWZ specifications by using implementation start and end dates in our data.

Table 3 displays the HWZ estimates of the impact of ERP adoption (defined as the “go-live” date) on performance between 1986 and 1998 in Row 1 (labeled as 1ERP) and our updated results (1998 to 2005) in Row 2 (labeled as 2ERP). Although we use a completely new dataset with no overlapping observations, our replication produces remarkably similar results, inspiring confidence in both analyses. The specification in which ERP adoption was statistically significant in the HWZ analyses are also significant in our new data set. The point estimates are also economically significant. For instance, the estimate of .104 in column (1) indicates that ERP adopters had, on average 10.4% greater labor productivity. While our results replicate the HWZ findings quite closely, we also find some significant improvements in the performance impacts of ERP in more recent years. Estimates of the impact of ERP adoption on ROA, inventory turnover, ROE, and profit margin are very similar, while asset utilization and collection efficiency show dramatic improvements in more recent data (Columns 6 & 7). The estimate of leverage (the debt to equity ratio, Column 8) also shows a larger parameter estimate (p <.10) while the estimate of labor productivity is smaller in magnitude though still highly significant. We find no measurable productivity returns to ERP adoption in Cobb-Douglas specifications (Column 9), echoing the results of HWZ.

Table 4. Returns to ERP - 1986-1998 & 1998-2005[7]

Test	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Labor Prod.	ROA	Invent Turn	ROE	Profit Mrgn.	Asset Util.	Collection Efficiency	Leverag.	Output (Prod.)
1ERP	.163***	-.073	.126***	-.085	-.036	-.016	.008	.106	-.017
86-98	(.048)	(.072)	(.061)	(.061)	(.073)	(.033)	(.043)	(.089)	(.017)
R^2	.91	.82	.86	.88	.82	.96	.92	.77	.98
Obs.	4069	4069	4069	4069	4069	4069	4069	4069	4069
2ERP	.104***	-.019	.133***	-.046	-.036	.148***	.085***	.166*	-.002
98-05	(.031)	(.048)	(.035)	(.049)	(.049)	(.027)	(.026)	(.080)	(.018)
R^2	.87	.77	.82	.77	.77	.91	.91	.62	.95
Obs.	4135	3160	3593	3095	3160	4302	4251	3669	4117
Notes: *** p<.001; ** p<.05; * p<.10									

[7] Table 1 combines the results from *separate* regressions on returns to ERP reported in the HWZ study (Row 1) and our current study (Row 2). Although their coefficients are not shown, each regression includes the control variables specified in equations 1 and 2. The parameter estimates represent "go-live" events from both studies.

Our results demonstrate that ERP adoption strongly influences operational performance (inventory turnover, asset utilization and collection efficiency) and labor productivity, but has a negligible impact on measures of financial return or profitability. These results motivate important questions about what has changed in the last decade. For example, what explains the strong positive impact of ERP adoption on collection efficiency and asset utilization in more recent data? There could be several explanations. ERP systems may have simply improved over time. Organizational practices and business processes that deal with sales and customer payments may have also matured or been more tightly integrated with enterprise systems. In addition, we may be picking up the effects of new enterprise IT innovations correlated with ERP that contribute to firm performance. For example, if ERP adoption is correlated with adoption of SCM and CRM, and if these technologies contribute to performance, then omitting them could upward bias our estimates of the returns to ERP.

4.2. Addressing Simultaneity Bias in the Returns to ERP

If endogeneity exists in the relationship between ERP adoption and performance, simple estimates of a single binary adoption variable may be measured with error. However, separate estimates of purchase and go-live events can attribute variance to the purchase decision and the installation and use of the technology separately.

If performance determines adoption we would expect to see positive and significant coefficient estimates of *purchase* events. If on the other hand adoption determines performance, we would expect to see performance positively associated with *go-live* events, and not with *purchase* events. As the results in Table 5 demonstrate, purchase events are uncorrelated with performance, or in the case of measures of income before extraordinary items but after expenses (i.e. ROA, ROE, Profit Margin), negatively correlated with performance.[8] Go-live events on the other hand are strongly correlated with higher labor

[8] We find that the purchase of ERP software is associated with a 12% reduction in income before extraordinary items but after expenses ($p < .01$), representing the approximate cost of purchasing ERP systems for firms in our sample. Firms also take on more debt when purchasing ERP systems during 1998-2005, whereas during 1986-1998 they did not. This may be evidence of

productivity, inventory turnover, asset utilization, collection efficiency and leverage. These estimates imply that simultaneity bias is not affecting our results and lend credibility to the argument that ERP adoption drives performance, rather higher performance compelling firms to adopt ERP.[9]

Table 5. Performance Comparisons During License Purchase and After Go-Live: *ERP*

Dependent Variable	ln(Sales)	ln(Pretax Income)	Ln(COGS)	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
ERP: Purchase	-.012 (.0264)	-.133** (.042)	-.001 (.033)	-.075 (.043)	-.118** (.043)	-.039 (.022)	-.004 (.020)	.145* (.066)
ERP: Go Live	.103*** (.031)	-.029 (.048)	.137*** (.037)	-.057 (.049)	-.046 (.049)	.147*** (.027)	.089*** (.025)	.163* (.080)
ln(Employees)	1.0003*** (.009)							
ln(Assets)		.955*** (.012)				.983*** (.011)		
ln(Inventory)			.906*** (.010)					
ln(Equity)				.989*** (.014)				.964*** (.021)
ln(Sales)					.969*** (.011)			
ln(Accounts Rcv)							.900*** (.007)	
Control Variables	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year
R^2	.87	.77	.82	.77	.76	.91	.91	.62
Observations	4135	3160	3593	3095	3160	4302	4251	3669
Notes: *** p<.001; ** p<.05; * p<.10								

4.3. Returns to Extended Enterprise Systems: SCM & CRM

We first estimated the returns to SCM and CRM go-live events alone. The results showed strong positive associations between SCM and CRM and labor productivity (SCM: $\beta = .352$, $p < .001$; CRM $\beta = .341$, $p < .001$), inventory turnover (SCM: $\beta = .187$, $p < .001$; CRM: $\beta = .288$, $p < .001$), ROE (SCM: $\beta = .146$, $p < .10$; CRM: $\beta = .362$, $p < .10$) and asset utilization (SCM: $\beta = .139$, $p < .001$; CRM: $\beta = .167$, p <

increased managerial confidence in the returns to ERP or a greater willingness of creditors to issue debt to firms for the purchase of ERP systems. It could be that ERP systems increase creditor confidence by making firms' financial activities more transparent.

[9] In addition, some firms who purchase ERP licenses never follow through to implement or go-live with the technology. Our data are able to pick up performance differences between firms who purchased ERP but never went live and those firms who saw the implementation through to use.

.05), and SCM showed a strong positive association with collection efficiency (β = .178, p < .001).[10] These results provided initial evidence of the greater impact of external systems on productivity and performance, although these specifications did not directly compare ERP, SCM and CRM. If firms adopt these systems in concert we must estimate them simultaneously to determine which systems truly drive performance and to control for SCM and CRM as possible omitted variables in ERP estimates. Table 6 presents the results of these analyses for financial performance metrics.

Table 6: Returns to ERP, SCM and CRM Evaluated Simultaneously[11]

Dependent Variable	ln(Sales)	ln(Pretax Income)	Ln(COGS)	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
ERP live	-.055*	-.097**	.100**	-.138**	-.107**	.134***	.036	.119
	(.029)	(.046)	(.040)	(.047)	(.048)	(.026)	(.027)	(.080)
SCM live	.373***	.150**	.125**	.205**	.099	.060**	.160***	.145
	(.040)	(.066)	(.045)	(.068)	(.067)	(.027)	(.033)	(.097)
CRM live	.219	.186	.218*	.314*	.128	.106*	-.042	-.095
	(.136)	(.167)	(.121)	(.186)	(.165)	(.059)	(.098)	(.269)
Control Variables	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year
R^2	.87	.77	.82	.77	.77	.91	.91	.62
Observations	4135	3160	3593	3095	3160	4302	4251	3669

Notes: *** p<.001; ** p<.05; * p<.10

When all three suites of enterprise systems are estimated simultaneously, the positive impact of ERP on performance is to some degree explained by SCM and CRM.[12] Although our parameter estimates of the returns to ERP are very similar to the HWZ studies when ERP is evaluated alone, some of the positive impact of ERP on performance is explained by SCM and CRM when all three module suites are evaluated together. In estimates of ERP alone, we saw positive correlations with labor productivity, inventory turnover, asset utilization and collection efficiency (and negative correlations with profit variables e.g. ROA, ROE, and Profit Margin - see Tables 3 and 4). Controlling for the impact of SCM and

[10] Table omitted due to space constraints but available upon request.

[11] We do not report control variable estimates in Table 6 as they behave similarly in all analyses. They are available upon request.

[12] We have a limited number of observations of CRM adoption and use. Thus, while parameter estimates are quite large, confidence intervals remain wide making statistically significant estimates difficult to observe.

CRM, the correlations remain positive, but are reduced in magnitude and significance, the impact of ERP on labor productivity becomes slightly negative (although marginally significant), and the impacts of ERP adoption on ROA, ROE and Profit Margin remain negative but become significant. Estimates of the impact of ERP adoption on productivity behave similarly to the labor productivity estimate (see Tables 6 & 7). When all three variables are entered simultaneously, SCM and CRM are positively correlated with productivity and performance while the returns to ERP adoption are mitigated and, in the case of productivity, become negative.[13]

Table 7: Productivity Estimates for ERP, SCM and CRM Evaluated Simultaneously

Dependent Variable	ln(Output)	ln(Output)
Column	(1)	(2)
Ln(Capital)	.204*** (.009)	.202*** (.009)
Ln(Labor)	.229*** (.016)	.232*** (.016)
Ln(Material)	.569*** (.016)	.566*** (.016)
ERP live	-.002 (.017)	-.041** (.018)
SCM live		.120*** (.021)
CRM live		.059 (.037)
Control Variables	Industry Year	Industry Year
R^2	.95	.95
Observations	4117	4117
Notes: *** p<.001; ** p<.05; * p<.10		

These results suggest our original estimates of ERP are measured with error. The omission of SCM and CRM creates an upward bias in estimates of ERP alone. We consider four possible explanations for these results: omitted variables bias, the delayed performance effects of ERP, a selection effect that separates successful ERP implementers from unsuccessful ones, and complementarities across 'systems' of process enabling IT. Regardless of the interpretation, our estimates demonstrate bias associated with estimates of these systems in isolation.

[13] The SCM parameter estimate is highly significant and the CRM estimate is only marginally insignificant (p < .11).

Explanation 1: Omitted Variables Bias

One interpretation of the upward bias in estimates of ERP alone is that ERP is a proxy for the positive performance impacts of the omitted variables (SCM and CRM). SCM and CRM may simply explain part of the performance benefits originally attributed to ERP. Although estimates of the performance effects of ERP are mitigated by this, it is unlikely that ERP has *no* performance effect absent SCM and CRM. McAfee (2002) finds strong positive performance effects from ERP in the absence of SCM and CRM, and Hitt et al. (2002) find positive ERP performance impacts during a period when SCM and CRM were almost non-existent or at least not widespread enough to drive their results.

Explanation 2: Delayed Performance Effects of ERP

The positive performance impacts of SCM and CRM could also be picking up delayed performance effects of ERP systems adopted a few years before. This explanation is consistent with evidence suggesting a delayed performance effect of IT (Brynjolfsson & Hitt 2003). The performance effects of ERP may not be realized until up to three years after implementation and sometimes longer (e.g. O'Leary 2000), in part because organizational changes and intangible investments in human capital and new business processes take time to implement. If the lagged effect of ERP is omitted from our estimation, we may incorrectly attribute the delayed performance impacts of ERP to SCM and CRM. To evaluate this alternative explanation, we employed a simple distributed lag specification including three years of lagged ERP adoption.[14]

[14] We use three years of ERP lags to conform to prior estimates of the lag time to ERP benefits (e.g. Hendricks et al. Forthcoming). However, inclusion of fewer or more lags does not significantly change our results. Lagged variables represent instances of lagged "go-live" events.

Table 8: Performance Returns to SCM and CRM, and Lagged Estimates of ERP[15]

Dependent Variable	ln(Sales)	ln(Pretax Income)	Ln(COGS)	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
ERP Live	-.027 (.053)	-.013 (.088)	.061 (.070)	-.069 (.088)	-.005 (.092)	.103** (.049)	.059 (.053)	.032 (.147)
L1.ERP Live	.041 (.063)	-.043 (.099)	.072 (.075)	-.038 (.096)	-.061 (.106)	.039 (.051)	-.011 (.061)	.093 (.163)
L2.ERP Live	-.065 (.062)	-.157 (.103)	-.001 (.070)	-.129 (.103)	-.184* (.109)	.015 (.045)	.034 (.055)	.062 (.153)
L3.ERP Live	-.031 (.054)	.109 (.094)	.045 (.064)	.106 (.099)	.095 (.099)	.039 (.039)	-.005 (.048)	.047 (.138)
SCM Live	.356*** (.042)	.136** (.070)	.110** (.047)	.208** (.072)	.114 (.072)	.062** (.029)	.182*** (.034)	.192* (.104)
CRM Live	.229* (.137)	.168 (.168)	.227* (.119)	.303 (.188)	.128 (.168)	.107* (.056)	-.027 (.099)	-.040 (.268)
Control Variables	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year
R^2	.87	.77	.82	.75	.74	.90	.91	.58
Observations	2539	1803	2180	1773	1803	2601	2574	2203

Notes: *** p<.001; ** p<.05; * p<.10.

Table 9: Productivity Returns to SCM and CRM, and Lagged Estimates of ERP

Dep. Var.	ln(Output)	ln(Output)
Column	(1)	(2)
ln(Capital)	.199*** (.012)	.194*** (.013)
Ln(Labor)	.242*** (.021)	.248*** (.021)
Ln(Material)	.564*** (.019)	.559*** (.020)
ERP Live:	.038 (.030)	-.011 (.031)
L1.ERP Live	-.011 (.035)	-.011 (.034)
L2.ERP Live	-.032 (.032)	-.032 (.032)
L3.ERP Live	-.021 (.029)	-.016 (.029)
SCM Live		.126*** (.023)
CRM Live		.066* (.038)
Control Variables	Industry Year	Industry Year
R^2	.94	.94
Observations	2529	2529

[15] We do not report control variable estimates in Table 8 as they behave similarly in all analyses. They are available upon request.

The delayed performance effects of ERP do not explain the performance effects of SCM and CRM indicating that these systems have a significant positive effect on performance beyond that of the delayed effect of ERP. We find similar results in the Cobb-Douglas productivity specifications.

Explanation 3: A Selection Effect

It could also be that only firms that are successful with ERP implementations go on to purchase and implement SCM and CRM. If unsuccessful ERP implementers tend not to purchase and implement SCM and CRM, then our SCM and CRM variables will empirically separate 'successful' ERP implementers from 'unsuccessful' ones. Our parameter estimates of SCM and CRM could therefore be 'contaminated' by both the organizational characteristics of firms that are successful ERP adopters (time invariant characteristics and organizational changes made during successful ERP implementation) and the benefits of ERP. These effects could upward bias estimates of SCM and CRM and downward bias estimates of ERP by leaving only unsuccessful ERP implementations in the sub-sample of firms that do not adopt SCM or CRM.

To evaluate this proposition, we created a variable called 'ERP only' which tracks firms that have only adopted ERP and have not adopted any other suites (SCM or CRM) at a given time index. We then compared firms that only adopt ERP to firms that adopt SCM and CRM. As all firms who adopt SCM and CRM in our data have adopted ERP, this analysis in effect compares those firms that only adopt ERP (labeled as "ERP Only") to those that go on to adopt SCM and/or CRM (labeled as "ERP Plus"). If the selection effect exists in our data, we expect to see negative performance impacts of 'ERP only' firms and positive performance impacts of 'ERP Plus' firms, as 'ERP only' firms are more likely to less successful ERP adopters.

Table 10: Performance Effects of 'ERP Only' vs. 'ERP Plus'[16]

Dependent Variable	Ln (Sales)	ln(Pretax Income)	Ln (COGS)	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	Invntry Turn.	ROE	Profit Margin	Asset Utilization	Collection Efficiency	Leverage
ERP Only	-.077* (.032)	-.109* (.050)	.021 (.043)	-.142** (.051)	-.072 (.052)	.093*** (.027)	-.011 (.029)	.192* (.080)
ERP Plus SCM or CRM	.327*** (.040)	.097 (.064)	.209*** (.043)	.136* (.068)	.064 (.065)	.158*** (.028)	.131*** (.030)	.198* (.096)
Control Variables	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year
R^2	.87	.77	.82	.77	.76	.91	.91	.62
Obs.	4135	3160	3593	3095	3160	4302	4251	3669
Notes: *** p<.001; ** p<.05; * p<.10.								

When firms that only adopt ERP are compared to those that adopt ERP plus SCM and CRM, they exhibit a negative correlation with productivity and performance while firms implementing the full suite of extended enterprise systems perform significantly better across all performance dimensions.

Table 11: Productivity Effects of 'ERP Only' vs. 'ERP Plus'

Dep. Var.	ln(Output)
Column	(1)
ln(Capital)	.201*** (.009)
Ln(Labor)	.232*** (.016)
Ln(Material)	.567*** (.016)
ERP Only:	-.049** (.018)
ERP Plus SCM	.080*** (.023)
ERP Plus SCM & CRM	.113** (.046)
Control Variables	Industry, Year
R^2	.95
Observations	4117
Notes: *** p<.001; ** p<.05; * p<.10	

[16] Table 10 shows the results of regressions including a dummy variable for firms that adopted ERP only and another dummy variable for firms that adopted ERP and either SCM, CRM or both. These sets of firms are mutually exclusive by year and the variables are entered simultaneously into the regressions along with the appropriate controls.

Explanation 4: Complementarities

There may also be complementarities among ERP, SCM and CRM systems. ERP systems provide integrated data, processes and interfaces that enable effective execution of supply chain activities and utilization of customer data. Information inputs from supply chain partners can directly influence or automate planning of internal production activities, and production planning information can help supply chain partners optimize distribution and logistics. Mithas et al. (2005) find that firms with greater supply chain integration are more likely to benefit from their CRM applications and achieve improved customer knowledge. However, robust measurement of complementarities requires evidence of both the covariance or 'clustering' of complementary elements and the positive effects of the co-presence of complements on performance (Milgrom & Roberts 1990; Bresnahan et al. 2002).[17] In our data, SCM and/or CRM adopters are a perfect subset of firms that adopt ERP, thus traditional tests of complementarity are not possible with our data. Any SCM or CRM variable will be perfectly collinear with an interaction term interacting SCM or CRM with ERP adoption. Although we cannot confirm complementarity, we cannot rule it out as a possible explanation. In fact, in the presences of strong complementarities and rational management, adoption should be perfectly collinear.

4.4. Addressing Simultaneity Bias in the Returns to SCM and CRM

Our first set of estimates provide clear evidence of a unidirectional causal relationship between ERP and performance: ERP => performance. Of the four alternative explanations concerning SCM and CRM, two (Omitted Variables Bias and Complementarity) predict that the performance benefits to SCM and CRM systems should be associated with their *use* and *not their purchase*, while the other two (Selection Effect and Lagged ERP Effects) are compatible with positive performance effects associated with the *purchase* of SCM and CRM. Since we have evidence that the lagged benefits of ERP cannot fully explain the benefits associated with SCM and CRM (see Table 8), if performance is associated with the *purchase* of SCM and CRM systems, then we have compelling evidence for our main theoretical

[17] Typical empirical tests of complementarity estimate the degree to which hypothesized complements co-vary and whether they exhibit reinforcing interaction effects on firm performance (Athey & Stern 1998).

argument – that as firms succeed with IT, they invest in and adopt more IT systems. If on the other hand, SCM and CRM *purchase* events are *uncorrelated* with performance, but *go-live* events are *positively* correlated with performance, then our main argument is not supported and we instead have evidence of a strictly unidirectional causal relationship: IT => performance (e.g. ERP => Performance and SCM/CRM => Performance). If SCM and CRM are correlated with positive performance gains at *both* purchase and go-live, then we have evidence of a 'virtuous cycle' in which firms adopt the baseline ERP platform, see direct causal performance gains that then inspire firms to purchase SCM and CRM, after which SCM and CRM add additional value beyond that which can be explained by the lagged effects of ERP or by SCM or CRM *purchase* events. Appendix A provides a summary of five possible causal stories about the relationship between IT and firm performance and the evidence required to support each of them.

Table 12: Performance Comparisons During License Purchase and After Go-Live: *SCM*

Dependent Variable	ln(Sales)	ln(Pretax Income)	Ln(COGS)	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
SCM: Purchase	.087** (.031)	-.034 (.045)	.170*** (.039)	.017 (.047)	-.023 (.047)	-.036 (.027)	.063** (.022)	.025 (.074)
SCM: Live	.321*** (.037)	.074 (.062)	.142*** (.040)	.104 (.064)	.021 (.063)	.129*** (.026)	.146*** (.028)	.196* (.089
Control Variables	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year
R^2	.87	.77	.82	.77	.77	.91	.91	.62
Observations	4135	3160	3593	3095	3160	4302	4251	3669
Notes: *** p<.001; ** p<.01; * p<.05								

Tables 12 and 13 display the results of purchase and go-live analyses of SCM and CRM. The strongest positive correlations with performance are estimated after go-live events. But, purchase events are also clearly positively associated with performance, casting doubt on three of the first four causal interpretations outlined in Appendix. These results could be consistent with either the "classic simultaneity" or the "virtuous cycle" explanations. However, the unidirectional causal relationship between initial ERP investments and performance ultimately lend the most credibility to the "virtuous cycle" interpretation as one would have to tell a convoluted story as to why we see such strong simultaneity in SCM and CRM estimations but not in ERP estimations, especially given controls for temporal and industry specific shocks.[18]

Table 13: Performance Comparisons During License Purchase and After Go-Live: *CRM* [19]								
Dependent Variable	ln(Sales)	ln(Pretax Income)	Ln(COGS)	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
CRM: Purchase	.156** (.046)	.049 (.091)	.099* (.049)	.116 (.101)	-.085 (.096)	.072 (.042)	.057 (.034)	-.222 (.162)
CRM: Live	.236 (.136)	.155 (.171)	.178 (.132)	.268 (.198)	.147 (.170)	.102 (.066)	-.039 (.101)	-.013 (.287)
Control Variables	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year
R^2	.87	.77	.82	.77	.77	.90	.91	.62
Observations	4135	3160	3593	3095	3160	4302	4251	3669
Notes: *** p<.001; ** p<.01; * p<.05								

As a robustness check and to make sure our results were not an artifact of our estimation strategy, we independently estimated the impact of higher performance on the likelihood of purchasing ERP, SCM and CRM systems using the standard logistic regression model formalized in Equation 3. If simultaneity were not effecting any of the results we would expect no impact (or a negative impact) of performance on the likelihood of purchasing IT. What we see however is evidence that performance predicts the purchase of later stage SCM and CRM investments but not the initial ERP investments, corroborating our other evidence (Table 14).

Together these results not only support the "virtuous cycle" interpretation, they explicitly reject some portions of each of the other interpretations. In the end, we are left with compelling large-sample statistical evidence of one causal interpretation of the relationship between IT and firm performance in the context of enterprise systems – a "virtuous cycle" of snowballing IT investments driven by rational economic decision making that compels firms to invest in high marginal return assets like IT.

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[18] If these results were an artifact of delayed ERP benefits rather than a selection effect, we would expect to see the positive coefficients of SCM and CRM at purchase go away when we control for lagged values of ERP. However, including lagged values of ERP does not qualitatively change the results.

[19] We do not report control variable estimates in Tables 12 and 13 as they behave similarly in all analyses. They are available upon request.

Table 14. Logistic Regression Predicting the Impact of Prior Performance on the Probability of Adopting ERP, SCM and CRM

Dependent Variable	Likelihood of Purchasing ERP	Likelihood of Purchasing SCM	Likelihood of Purchasing CRM
Column	(1)	(2)	(3)
ln(Sales/Employees)	-.062	.212***	.319**
	(.057)	(.059)	(.107)
ln(Cogs/Inventories)	-.021	.173***	.007
	(.045)	(.050)	(.074)
ln(Sales/Assets)	.117	-.212**	.225
	(.084)	(.090)	(.194)
ln(Sales/Accts Rcv)	-.116*	.082	-.039
	(.068)	(.073)	(.134)
Control Variables	Industry Year	Industry Year	Industry Year
Log Likelihood	-1867.96	-1611.23	-616.16
Chi-Square (D.F.)	61.61***	271.82***	62.24***
	(19)	(19)	(15)
Pseudo-R^2	.017	.096	.063
Observations	3031	3031	2509

5. Conclusion

Whether or not IT *causes* productivity and performance increases is a critical questions in industrial organization and productivity research. Studies of IT value have used successively more sophisticated econometric methods to try to disentangle causality in the IT-performance relationship with mixed results. Generally speaking, good instrumental variables are hard to find. They are usually either too weak to provide explanatory power or not exogenous enough to definitively address reverse causality.

In this paper, we approach the causality question from a new angle – the use of detailed data that separates observation of purchasing decisions from observation of IT implementation and use. Our empirical strategy highlights a new tool with which to tease apart casualty in the IT business value literature. We use this tool in the context of enterprise systems, one of the largest and most ubiquitous categories of IT investment at the enterprise level. Our results (1) shed light on the likely causal direction of the relationship between IT and performance, (2) provide up-to-date estimates of the impact of enterprise systems, (3) identify new issues in the estimation of returns to systems of process enabling IT, and (4) provide new evidence of the differential returns to internal and external IT adoption.

Most importantly, our results reveal a new perspective with which to view causality in IT value research. We find evidence that ERP *causes* performance increases rather than performance inspiring ERP purchases. We then demonstrate that success with ERP encourages adoption of extended enterprise systems, which in turn improve operational performance and productivity. Our results support the view that a "virtuous cycle" exists in the relationship between IT investment and performance, such that initial investments drive performance gains, which in turn encourage further investment. Furthemore, we demonstrate that this cycle plays out over the course of several years. Our data contradict most of the alternative views of causality previously debated in the IT literature and our perspective fits with rational economic theory that predicts investments will be made in assets with the highest marginal return. With this work we hope to open a new direction of inquiry into IT value.

References

Andersen, E.W., and Sullivan, M.W. "The Antecedents and Consequences of Customer Satisfaction for Firms," *Marketing Science* (12:2), 1993, pp. 125-143.

Aral, S. and Weill, P. "IT Assets, Organizational Capabilities and Firm Performance: Do Resource Allocations and Organizational Differences Explain Performance Variation?" MIT Sloan School, CISR Working Paper #356, 2006.

Arellano, M., and Bond, S.R. 1991. "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations," *Review of Economic Studies* (58:2), 1991, pp. 277-297.

Athey, S., and Stern, S. "An Empirical Framework for Testing Theories about Complementarity in Organizational Design," NBER Working Papers 6600, 1998.

Austin, R.D., Nolan, R.L., and Cotteleer, M.J. 2002. "Cisco Systems, Inc.: Implementing ERP," Harvard Business School Case 9-699-022.

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

Bharadwaj, A. S., Bharadwaj, S. G., and Konsynski, B. R. "Information Technology Effects on Firm Performance as Measured by Tobin's q," *Management Science* (45:7), 1999, pp. 1008-1024.

Bresnahan, T., Brynjolfsson, E., and Hitt, L. M. "Information Technology, Workplace Organization and the Demand for Skilled Labor: Firm-level Evidence," *Quarterly Journal of Economics* (117:1), 2002, pp. 339-376.

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

Brynjolfsson, E., and Hitt, L.M. "Beyond Computation: Information Technology, Organizational Transformation and Business Performance," *Journal of Economic Perspectives* (14:4), 2000, pp. 23-48.

Brynjolfsson, E., and Hitt, L.M. "Computing Productivity: Firm-Level Evidence," *Review of Economics and Statistics* (85:4), 2003, pp. 793-808.

Cachon, G. P., and Fisher, M. "Supply Chain Inventory Management and the Value of Shared Information," *Management Science* (46:8), 2000, pp. 1032-1048.

Clemons E. K., Reddi, S. P., and Row, M. "The Impact of Information Technology on the Organization of Economic Activity: The Move to the Middle Hypothesis," *Journal of Management Information Systems* (10:2), 1993, pp. 9-35.

Coase, R.H. "The Nature of the Firm," *Economica N.S.* (4:16), 1937, pp. 386-405.

Cohen, M.A., Agrawal N., and Agrawal V. "Winning in the Aftermarket," *Harvard Business Review* (May), 2006, pp. 129-138.

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

Fisher, M.L. "What is the Right Supply Chain for Your Product?" *Harvard Business Review* (March-April), 1997, pp. 105-116.

Gao, G., and Hitt, L.M. "IT and Product Variety: Evidence from Panel Data," in *Proceedings of the 25th Annual International Conference on Information Systems*, Agaral, R. and Kirsch, L. (Eds), Washington, D.C., December 2004: Association for Information Systems.

Griliches, Z., and Mairesse, J. "Production Functions: The Search for Identification," NBER Working Papers 5067, National Bureau of Economic Research, Inc., 1995.

Hendricks, K.B., and Singhal, V. R. "Association between Supply Chain Glitches and Operating Performance," *Management Science* (51:5), 2005, pp. 695-711.

Hendricks, K. B., Singhal, V. R., and Stratman, J. K. "The Impact of Enterprise Systems on Corporate Performance: A Study of ERP, SCM, and CRM System Implementations," *Journal of Operations Management*, forthcoming.

Hitt, L.M. "Information Technology and Firm Boundaries: Evidence from Panel Data," *Information Systems Research* (10:2), 1999, pp. 134-149.

Hitt, L.M., Wu, D. J., and Zhou, X. "Investment in Enterprise Resource Planning: Business Impact and Productivity Measures," *Journal of Management Information Systems* (19:1), 2002, pp. 71-98.

Hogan, J. E., Lemon, K. N., and Rust, R.T. "Customer Equity Management: Charting New Directions for the Future of Marketing," *Journal of Service Research* (5:1), 2002, pp. 4-12.

Holmstrom, B., and Roberts, J. "The Boundaries of the Firm Revisited," *Journal of Economic Perspectives* (12), 1998, pp. 73-94.

Ichniowski, C., Shaw, K., and Prennushi, G. "The Effects of Human Resource Management Practices on Productivity: A Study of Steel Finishing Lines," *American Economic Review* (87:3), 1997, pp. 291-313.

Jensen M. C., and Meckling, W. H. "Theory of the Firm: Managerial Behavior, Agency Costs, and Ownership Structure," *Journal of Financial Economics* 3**,** 1976, pp. 295-316.

Lee, H., V. Padmanabhan, S. Whang. "Information Distortion in a Supply Chain: The Bullwhip Effect," *Management Science* (43:4), 1997, pp. 546-558.

Markus, L.M, Tanis, C., and van Fenema, P.C. "Multisite ERP Implementations," *Communications of the ACM* (43:4), 2000, pp. 42-46.

McAfee, A. "The Impact of Enterprise Technology Adoption on Operational Performance: An Empirical Investigation," *Production and Operations Management Journal* (11:1), 2002, pp. 33-53.

McAfee, A. "When Too Much IT Knowledge is a Dangerous Thing," *MIT Sloan Management Review* (44:2), 2003, pp. 83-89.

Melville, N., Kraemer, K., and Gurbaxani, V. "Review: Information Technology and Organizational Performance: An Integrative Model of IT Business Value," *MIS Quarterly* (28:2), 2005, pp. 283-322.

Milgrom, P., and Roberts, J. "The Economics of Modern Manufacturing: Technology, Strategy and Organization," *American Economic Review* (80:3), 1990, pp. 511-528.

Mithas, S., and Krishnan, M.S. "Causal Effect of CRM Systems on Cross Selling Effectiveness and Sales-force Productivity by Bounding a Matching Estimator," in *Proceedings of the Ninth Annual INFORMS Conference on Information Systems and Technology,* Bhargava, H., C. Forman, R. Kauffman, D.J. Wu (eds.), Denver, CO, 2004.

Mithas, S., Krishnan, M. S. and Fornell, C. "Why Do Customer Relationship Management Applications Affect Customer Satisfaction?" *Journal of Marketing* 69, 2005, pp. 201-209.

Mukhopadhyay, T., Rajiv, S., and Srinivasan, K. "Information technology impact on process output and quality," *Management Science* (43:12), 1997, pp. 1645-1659.

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

Olley, S., and Pakes, A. "The Dynamics of Productivity in the Telecommunications Equipment Industry," *Econometrica* (64:6), 1996, pp. 1263-1298.

Swanson, E.B., and Wang, P. "Knowing Why and How to Innovate with Packaged Business Software," Working Paper, The Anderson School at UCLA, Los Angeles, CA, 2003.