

Scale without Mass: Business Process Replication and Industry Dynamics

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Abstract

In the mid-1990s, productivity growth accelerated sharply in the U.S. economy. In this paper, we identify several other changes that have occurred during the same time and argue that they are consistent with an increased use of information technology (IT) in general and enterprise IT in particular. Case studies and econometric evidence demonstrate that IT has enabled firms to more rapidly replicate improved business processes throughout an organization, thereby not only increasing productivity but also market share and market value. We develop a simple model that shows how IT-enabled business process replication will also increase both turbulence and concentration at the industry level. We then document a substantial increase in turbulence starting in the 1990s, as measured by the average intra-industry rank change in sales, enterprise value, and other metrics. In particular, we find that IT-intensive industries account for most of this increase in turbulence, especially after 1996. In addition, we find that IT-intensive industries became more concentrated than non IT-intensive industries after 1996, reversing the previous trend. The combination of increased turbulence and concentration, especially among IT-intensive industries, is consistent with an increasingly Schumpeterian style of competition. We conclude that the improved ability of firms to replicate business innovations is linked not only to productivity increases, but also to changes in the nature of business competition itself.

Key words: Business Process Replication; Creative Destruction; Information Technology; Turbulence; Concentration;

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1 Introduction: IT Heterogeneity and its Implications

The US economy has become substantially more IT intensive in recent years. Figure 1a plots IT's percentage of total investment in tangible wealth each year from 1987 to 2004, together with the equivalent percentages for equipment and plant (the three values for each year sum to 100). IT's share of the total nearly doubled during this period, to over 23% of total tangible wealth. Figure 1b, which plots IT stock per full-time employee (FTE) in the US over the same period, shows that annual increases in this measure were particularly large in the latter half of the 1990s when several novel technologies appeared. By 2004, at more than \$2,600, it was at a record high, more than three times higher than it had been in 1987. What's more, because IT is delivering more power per dollar, these increases in spending dramatically understate the amount of real computing power delivered and the consequent potential for changing business strategy, structure and performance. In total the real, quality-adjusted quantity of computing power used by American companies increased by over 33-fold within the past twenty years (Figure 1c).

A stream of economics research has focused on articulating the consequences of this rapid penetration of IT into the U.S. economy. A key finding has been that the linkage between IT investment and the surge in U.S. economic productivity has been a strong one, especially since 1995 (Brynjolfsson and Hitt 2000, Oliner and Sichel 2000, Stiroh 2002, Brynjolfsson and Hitt 2003, Dedrick et al. 2003). A second consistent finding has been that neither IT endowments nor their impacts are evenly distributed (Kohli and Devaraj 2003). IT investment levels themselves vary greatly across firms and industries, as do the organizational forms and practices accompanying these investments (Bresnahan et al. 2002) and the outcomes linked to them, including productivity and revenue gains (Brynjolfsson and Hitt 1996, Dedrick et al. 2003, Brunner et al. 2006), stock market valuations (Brynjolfsson and Yang 1997, Brynjolfsson et al. 2002, Im et al. 2001), levels of vertical integration and diversification (Hitt 1999, Dewan et al. 1998) and share-price volatility (Chun et al. 2005).

However, there has been little systematic research on the competitive implications of recent IT investments in the US or elsewhere. It is not known if the increasing penetration of IT into firms and in-

dustries has been accompanied by significant shifts in firms' competitive positions and industries' dynamics, and whether these shifts (if they exist) have been consistent or divergent across sectors. Diametrically opposed arguments have been advanced. Some argue that IT can be a source of sustained competitive advantage (McFarlan 1984, Mata et al. 1995, Prahalad and Krishnan 2002) while others argue that 'IT doesn't matter' – it is a “cost of business that must be paid by all but provides distinction to none” (Carr 2003). To date, the evidence in support of both arguments has consisted primarily of case studies.

Case studies provide valuable fodder for theory building, but larger samples can better address questions of generalizability. Accordingly, this paper extends research on the impact of IT by statistically assessing two outcomes related to competition: growth in concentration, which reflects the extent to which an industry is dominated by a few large firms, and turbulence, which we define as the level of year-to-year instability in firms' rank order in sales or enterprise value. In the economy as a whole, both of these metrics have increased substantially since the mid-1990s. Interestingly, we find that a positive relationship has existed since the mid-1990s between an industry's IT intensity and its levels of both turbulence and concentration growth.

We hypothesize that IT has become a means of not only embedding business innovations, but also replicating them with high fidelity across an arbitrarily large intra-firm “footprint.” Today, managers can scale up their process innovations rapidly via technology without the degree of inertia historically associated with larger firms. In other words, they can achieve scale without mass.

However, we also hypothesize that these innovations do not diffuse equally across all firms in an industry. Firms that successfully use IT to embed and diffuse innovations grow relatively rapidly at the expense of other firms, leading to winner-take-all dynamics and hence greater concentration at the industry level. Because firms operate in dynamic environments, however, successful adoption of a set of IT-enabled business innovations at one point in time does not guarantee sustained dominance. Competitors and new entrants can also innovate and replicate with IT over time, leading to high levels of turbulence within an industry. These phenomena are more salient in IT-intensive industries than in non IT-intensive ones.

This paper is organized as follows. Section 2, which makes use of several short case examples, describes how contemporary IT is used to embed and replicate business innovations, and why this work could be expected to lead to competitive heterogeneity across firms in an industry. Section 3 presents a simple model of competition which shows how, over time, both concentration and turbulence will increase as IT-enabled replication becomes more prevalent. Section 4 describes our data sources and variables, and Section 5 gives results of empirical analyses that make use of industry-level IT endowment and firm-level performance data. These analyses indicate that, since the mid-1990s, IT-intensive industries have experienced higher levels of turbulence and concentration growth than have non-IT-intensive ones and that these industry differences were not as strong when IT stock was smaller in magnitude and less pervasive. Section 6 presents a brief summary and conclusion.

2 IT and Business Process Replication

The ability to replicate best practices within a firm is critical to building competitive advantage. However, traditionally process replication has often been found to be difficult (Szulanski 1996, Winter and Szulanski 2001, Szulanski and Winter 2002). From the beginning, information technology has made it possible to replicate certain types of innovation at little or no marginal cost, namely those that could be completely embedded in digital form, such as software, database and more recently music (Shapiro and Varian 1999). For example, when a software engineer improves a sorting algorithm in a database management program, a digital copy of that improved process can be instantly copied and included in thousands or even millions of copies of the next release of that program. The high productivity levels and productivity growth rates software firms is one consequence of this fact.¹ However, so is the Schumpeterian competition in this industry. Firms which develop better software applications can rapidly grow to dominate the industry, or even create whole new sectors. At the same time, their dominance is far from assured, with many indus-

¹ For instance, Brynjolfsson and Kemerer (1993) found that the quality adjusted improvements in spreadsheet software were 10% or more per year.

try leaders losing their position, or even failing altogether, when competitors or new entrants develop a superior product.

The Internet has broadened the set of activities subject to this phenomenon to include an increasing share of commerce (Blinder 2000). Today, for example, when a marketing expert at Amazon.com develops a better sequence of images, words, and data requests for reducing abandoned “shopping carts” on the site’s check-out page, a digital copy of that algorithm can instantly be made available in millions of virtual storefronts on customer desktop PCs worldwide. Thus, an innovation affecting customers in one location instantaneously becomes an innovation for customers in millions of locations. This is fundamentally different, in speed, fidelity and impact, from innovations in traditional retailing.

It is easy to see the power of replication in these purely digital domains. But economic impacts also derive from business process changes that involve technology, people, and physical products. An early, if somewhat limited, example was Mrs. Fields Cookies (Cash and Ostrofsky 1986). Randy Fields sought to replicate not only his wife’s cookie recipes throughout thousands of small stores, but also the daily, minute-by-minute routine that made her initial Palo Alto store so successful, including what times each day to mix each cookie batch, when to dispose of unsold cookies, when to offer more free samples, what questions to ask of job applicants, and so on. As better business processes were developed, they were embedded in store management software that guided all employees worldwide. Other franchisors and chain stores have been early exemplars of the power of such business process replication, although the ability to monitor and enforce compliance has always been imperfect.

Enterprise Information Technology

In the mid 1990s, the use of technology to embed and replicate business processes became dramatically more sophisticated and pervasive, addressing industries far more complex than cookie baking. In 1992, the German IT vendor SAP released R/3, an enterprise system with client-server architecture. R/3 quickly proved popular with large corporations, and other software vendors soon released enterprise information technology (EIT) aimed at different types of firms (e.g., large vs. medium-sized, discrete vs.

continuous manufacturing) and different business processes (e.g. customer-facing vs. supplier-facing, administrative vs. operational). Previously, firms that wanted integrated information systems had to develop them internally. The availability of commercial EIT in the mid 1990s meant that firms could instead purchase systems that interlinked their functions. By one estimate, up to three-quarters of all U.S. corporate IT spending is now devoted to EIT (McAfee 2003). This not only underscores the importance of EIT, but also suggests that aggregate IT spending is a serviceable proxy for EIT and vice versa.

The geographic reach of EIT was greatly increased by the Internet, which freed companies from having to construct private networks when extending their systems to remote locations. The period of time since the mid 1990s has been called the “Internet era,” but it can also be thought of as the era of enterprise computing. In their discussion of enterprise systems, Markus and Tanis (1999) assert that “Their potential significance for computer-using organizations cannot be overstated.”

The combination of Internet and enterprise technologies possibly contributed to the productivity growth pattern documented by Stiroh (2002), who found clear evidence of a positive association between IT intensity and productivity growth in many U.S. industries only since the mid-1990s. Oliner and Sichel (2000) lend support to the idea that IT’s noticeable impacts may in fact be recent ones. They remark that, until recently, IT represented only a relatively small portion of the capital stock of U.S. firms, and thus could not be expected to have a significant impact on high-level outcomes.

With EIT, insights about better ways to work need not remain localized or diffuse slowly; instead, they can be replicated widely and with complete technical fidelity. Just as a digital copy of a photograph or song can be endlessly copied and distributed with little or no degradation of quality, copies of EIT-embedded business processes are increasingly subject to similar economics. Enterprise technologies thereby give firms the capability to “copy exactly” the IT-based elements of their business processes. Exact copying of interdependent processes within firms has been shown to be optimal when initial knowledge is low, learning is difficult, and innovation lifecycles are short (Terwiesch and Wu 2004). EIT allows firms to propagate a wide range of operational and administrative processes across all appropriate units. A large body of research attests that this is difficult work and that success with an EIT initiative is

far from guaranteed (see, for example, McAfee 2003 and McDonagh 2001). For the present purposes, however, the salient fact is that enterprise systems, especially in combination with Internet technologies, represent a quantum leap forward in firms' abilities to replicate business processes with high fidelity.

Case Study: In 2002, the retail pharmacy firm CVS became concerned about high customer turnover and formed a team to determine root causes and implement solutions. The team found that the initial step in the process of filling prescriptions was a computer-based drug safety check, performed approximately one hour before the desired pick-up time. Immediately after the safety check, the firm's enterprise system for pharmacy operations performed a check of the customer's insurance status. If the prescription passed both of these steps, fulfillment was rarely problematic and could be completed in less than five minutes. However, 17% of prescriptions encountered problems during the insurance check, the majority of which could not be resolved without involving the customer.

The team decided to switch the order of the two computerized checks and to perform the insurance check at the time of prescription drop-off while the customer was still present. Both of these changes were embedded in the firm's EIT. Most insurance problems had simple sources, such as an incorrect date of birth or a change of employer, which were resolved immediately. The new process led to significant increases in customer retention and satisfaction. However, the key competitive factor was that, once developed, the changes did not simply improve performance at one CVS location. On the contrary, using the IT platform, the process changes were replicated across CVS's more than 4000 retail pharmacies within a year (McAfee 2005b). Thus, what had been a local innovation became an innovation that affected competition throughout the whole industry.

Other documented examples of business process replication via EIT include the Port Authority of Dubai's success in convincing both large and small shipping agents at numerous sites throughout the region to submit and clear cargo documents electronically rather than with paper (McAfee et al. 2002), and the Spanish clothing retailer Zara's ability to let local managers at over 750 stores worldwide place individualized orders using uniform technologies, templates, and deadlines (McAfee et al. 2004).

These examples illustrate how enterprise systems are used to replicate business processes across many sites. In addition, EIT can also be used to ensure process consistency not only across space, but also over time. Many companies have deployed enterprise technologies to ensure that procurement, human resource, financial, and expense reporting processes are executed the same every time. Case studies have also documented how firms have used EIT to standardize customer interactions. IBM, for example, automated the transmission of orders from its European distributors of midsize computers so that they all contained consistent information and were accepted and verified without human intervention. This led to increased labor productivity and faster cycle times (McAfee and Otten 2005). The mutual fund wholesaler Evergreen Investments deployed a customer relationship management system that captured details of all customer interactions in a consistent format; this information was used both by salespeople and management to plan future interactions (McAfee 2005a). These and other examples show that business process replication is valuable not only for geographically distributed companies, but instead universally. All firms have some set of repeatedly executed processes that would benefit from being standardized to 'best practices.'

It is important to note that business process replication is entirely consistent with decentralized of many key decision rights, and with local innovation. Zara's technology, for example, is explicitly designed to facilitate the rapid response to local tastes as perceived by store managers around the world. Similarly, the many information technologies that explicitly or implicitly facilitate collaboration and the propagation of ideas will amplify and accelerate productivity improvements which might have remained localized in earlier decades. Rather than monotonically shifting rights, IT may facilitate the centralization of some types of decisions, especially those involving quantifiable, transferable information and routines while decentralizing others, such as those that rely on tacit, local, knowledge (Brynjolfsson and Mendelson, 1993).

Difficulty of Inter-firm Propagation

While propagating novel IT-enabled novel business processes within a single firm can be challenging, propagating them across firms is typically far more challenging, at least with current technology and institutions. The process configuration that works well in one firm might not transfer well to one with a different culture, set of pre-existing routines, mix of incentives, asset base, and approach to human resources. Empirical research shows that many beneficial managerial practices are not universally diffused across firms (Bloom and Van Reenen 2005) and highlights the importance of complementarities in explaining the difficulty of diffusion (Ichniowski et al. 1997). While generic EIT software may be available to all firms in an industry, 80% or more of the costs of an EIT project are due to the firm-specific business practices and training (Brynjolfsson, Hitt and Fitoussi, 2003). Merely buying the same CRM system as Wal-Mart will by no means deliver similar customer relationship management processes.

This work suggests that the boundary of the firm is a significant barrier to the diffusion of IT-enabled work changes. This conclusion is supported by research on the heterogeneity of workplace reorganizations in the presence of IT (Bresnahan et al. 2002) and by research that reveals large differences in firm-level outcomes such as productivity growth even after controlling for IT investment (Brynjolfsson and Hitt 2000). It is also supported by simulations showing that searching for an optimal strategy, even one that has already been attained by a rival, is intractably complex, and that as a result would-be imitators must rely on heuristics and learning that are themselves undermined by complexity (Rivkin 2000). Particularly important for our purposes, simulations reveal that the gap between replicability and imitability -- between a firm's ability to copy its own internal practices and a rival's ability to perceive and mimic them -- is highest under two conditions: when practice complexity is at least moderately high, and when a practice template exists within the firm (Rivkin 2001). We view enterprise IT precisely as a process template.

Case Study: It became evident in the late 1990s that the discount retailer Kmart operated less efficiently than did competitor Wal-Mart. Specifically, Kmart suffered from poor inventory availability in its stores due to inadequate forecasting and fulfillment processes. Wal-Mart's operational excellence was

due in part to an integrated IT infrastructure that rapidly transmitted sales and inventory data from all stores to headquarters.

In October 2000, Kmart, whose previous large-scale IT initiatives had stumbled, announced a \$1.7 billion effort to change both its physical and IT infrastructures. This effort reflected a conscious strategy to adopt many of the processes of market-leading Wal-Mart. It did not succeed. In fall 2001, Kmart wrote off two distribution centers and IT assets related to the effort worth \$130 million while announcing a redirected \$600 million IT strategy. In January 2002, Kmart declared bankruptcy. The firm had had four chief information officers in the previous five years (Konicki 2002).

New Growth Theory and Creative Destruction

What changes to competitive dynamics could be expected to accompany increased business process replication via IT? The stream of economics scholarship known as new growth theory (Romer 1990, Romer 1994) provides some predictions in this area. Although new growth theory has typically focused on the national economy, rather than the firm, as the primary unit of analysis, its insistence that knowledge be treated endogenously make it applicable to our work. As the case studies given above illustrate, firms are using information technologies to embed and diffuse knowledge.

At least three of new growth theory's stylized facts seem applicable when considering the competitive impact of IT on firms in an industry. First, the theory asserts that while knowledge is non-rival, it is at least somewhat excludable (Romer 1990). That is, trade secrets, path dependence, intellectual property protection, and other mechanisms combine to give the generator of new knowledge the ability to at least partially exclude others from its benefits. The difficulties of inter-firm transfer of IT-enabled business processes provide evidence that knowledge continued to be excludable even after it's embedded in technology.

Second, new growth theory maintains that knowledge-based competition tends to become monopolistic over time (Romer 1992). Increasing returns to knowledge, a cornerstone of new growth theory, implies that leading firms will build up significant advantages over their rivals such that they become

monopolies. Knowledge-based competition, in other words, is associated with winner-take-all dynamics. This idea is consistent with the key insight that information itself can create economies of scale because of its relative ease of replication (Wilson 1975).

Monopolies are not eternal, however, because of a third stylized fact labeled “creative destruction” by Joseph Schumpeter. Competitive equilibria are repeatedly disturbed by innovation and new knowledge; consequently, new ways of working displace old ones. Outcomes and end states, as a result, become very difficult to predict (Romer 1994, Arthur 1996). One result that *can* be anticipated is that, as competition revolves increasingly around knowledge, Schumpeterian creative destruction becomes increasingly pronounced.

Case Study: In January 1998, brokerage Charles Schwab offered Internet-based stock trades to all of its customers for \$29.95 per trade, ending the previous tiered pricing structure. By December 1998, Schwab’s market capitalization surpassed that of Merrill Lynch, a firm with nearly three times as many client assets under management. Many analysts expected Merrill Lynch to also offer discounted online trading, but Schwab’s CEO remarked, “I don’t think Merrill will ever have two things that have been critical to our success. First, they will never embrace technology as the core of their business the way we do. Second, they will never have as low a cost structure as we do, which will make it hard for them to offer superior value” (McFarlan and Tempest 2001).

Merrill Lynch unveiled its “Integrated Choice” program in June 1999. Integrated Choice offered a range of trading support and investment advisory options; its most basic option was similar to Schwab’s, offering online trades for \$29.95. In tandem with the launch of Integrated Choice, Merrill Lynch made significant IT investments and changed the incentive structure of many of its employees (McFarlan and Weber 2001). Unlike the first generation of Web-based trading platforms, Merrill’s system focused not simply on low costs and simple execution of trades, but on a richer flow of information and advice that leveraged some of the unique assets, including a research staff, possessed by Merrill Lynch. The new offerings were well-received by customers, and Merrill began to acquire new client assets more rapidly than Schwab. By October 2005, Merrill Lynch’s market capitalization was almost four

times that of Charles Schwab. While advances in information technology had enabled Schwab to replicate a set of innovations and overtake Merrill Lynch with remarkable suddenness, related technologies in turn allowed Merrill Lynch to replicate a new set of business process and regain its market position equally quickly.

Hypotheses

Our broad hypothesis is that the combination of enterprise IT and the Internet substantially increased ease, speed, and fidelity of intra-firm business process replication. This led to more Schumpeterian competition and heightened winner-take-all dynamics. If this hypothesis is accurate, it has four testable implications. The hypothesis predicts that industries' levels of 1) turbulence and 2) concentration growth should be higher after the mid 1990s than before. Furthermore, we predict that 3) the increase in turbulence should be greater in more IT-intensive industries, as should 4) the increase in concentration. These predicts reflect our view that industry-level IT intensity can be viewed as a measure of the volume of business process replication activity taking place among firms in an industry. In comparatively IT-intensive industries the pace of IT-enabled business process change and replication is higher, and so too should be levels of turbulence and concentration growth.

It is important to note that this hypothesis is silent on why some industries might be more IT intensive than others, both before and after the mid 1990s. Industries have different competitive dynamics, and it is almost certainly true that firms have always purchased IT in part to help them respond to the competitive environment they face. Both of these observations, however, are irrelevant for the present purposes. Our hypothesis is silent on the *causes* of IT investment; it concerns only the *effects* of these investments. In this way, it parallels much of the literature on the productivity effects of IT (e.g. Stiroh, 2002). We hypothesize that these effects include increased turbulence and concentration growth at the industry level after the mid 1990s, and a stronger relationship between IT intensity and these competitive outcomes during this time. The next section formalizes these hypotheses.

3 Model

We use a stylized model to illustrate the impact of information technology on firm performance and industry structure. While IT can affect firms in many different ways, we focus on its role in improving firms' ability to replicate business process innovation.

Consider an industry with two competing firms, A and B . Assume the economy has n distinct locations or "cities" and each firm has one branch in every city. Let the branches be A_1, \dots, A_n for firm A and B_1, \dots, B_n for firm B . Assume A_i and B_i are competing in city i . While in our model firms are geographically distributed, our model applies equally well to cases in which the two firms are in one location, but has many interactions with distinct customers (which could similarly be indexed). We assume that n is large.

The marginal costs of A_i and B_i in period t are c_{it}^A and c_{it}^B . Assume there is one unit mass of consumers in each city. Consumer tastes in each city are homogeneous. Therefore, in equilibrium the branch with lower marginal cost can price its product just below its competitor's marginal cost and obtain 100% market share. That is, if in city i , $c_{it}^A < c_{it}^B$, then the market share of firm A in city i is 100%. The total market share of firm j , $j \in \{A, B\}$, in period t , is $MS_t^j = \sum_{i=1}^n MS_{it}^j$. We assume n is an odd integer to ensure that we always have a market share leader in each period.

We first examine the average rank change from period $t-1$ to t , measured by the average of the absolute rank change of market share for the two firms from period $t-1$ to t . Without loss of generality, assume that in period $t-1$, the total market share of firm A , MS_{t-1}^A , is greater than firm B .

Let $c_{min,t}^j = \min\{c_{1t}^j, \dots, c_{nt}^j\}$. Denote the difference between the costs, $c_{it}^A - c_{it}^B$, as Δc_{it} and the difference between the lowest costs, $c_{min,t}^A - c_{min,t}^B$, as $\Delta c_{min,t}$. As firms continue to innovate over time, we assume that $\Delta c_{min,t}$ is drawn from a uniform distribution in the interval $[-\beta, \beta]$ in each period, where $\beta > 0$ is a constant and is sufficiently large. $\Delta c_{min,t}$ is realized at the beginning of each period.

Further, we assume that Δc_{it} is uniformly distributed in the interval $[\Delta c_{min,t} - k, \Delta c_{min,t} + \alpha k]$. $k \geq 0$ captures firms' ability in replicating their business processes. k decreases as the ability improves. If each firm can perfectly replicate the business process with the lowest cost across all branches, $k = 0$ and the cost difference between the two firms is a fixed number, $\Delta c_{min,t}$, in each city. As firm A is the winner in period $t-1$, we assume that $0 < \alpha < 1$ to give firm A a small advantage: $E(c_{it}^A - c_{it}^B) < 0$ as $E(\Delta c_{min,t}) = 0$ and $0 < \alpha < 1$. The assumptions on uniform distributions are made for algebraic convenience. Our results hold qualitatively for any distributions with finite mean and variance.

Figure 3 illustrates the cost distributions of the two firms for $k > 0$ and $k = 0$. As the ability to replicate business process is positively correlated with IT intensity in the industry, we assume $k = f(IT_t)$, where $f(IT_t)$ is a continuous function of IT intensity at time t , $\frac{dk}{dIT_t} < 0$ and $\lim_{IT_t \rightarrow \infty} f(IT_t) = 0$.

As $MS_{t-1}^A > MS_{t-1}^B$, the average rank change is 0 when $MS_t^A > MS_t^B$ and is 1 when $MS_t^A < MS_t^B$. We have

$$\begin{aligned} E(\text{Rank Change}) &= 1 \cdot \text{Prob}(MS_t^A < MS_t^B) \\ &= \text{Prob}(MS_t^A < \frac{1}{2}) \end{aligned}$$

Let λ_i be the market share of firm A in city i . Hence

$$E(\lambda_i) = \text{Prob}(c_{it}^A < c_{it}^B) = \text{Prob}(\Delta c_{it} < 0) = \frac{k - \Delta c_{min,t}}{(1 + \alpha)k} = \frac{1}{1 + \alpha} - \frac{\Delta c_{min,t}}{(1 + \alpha)k}.$$

We have $MS_t^A = \sum_{i=1}^n \lambda_i/n$, where λ_i all have the same expected value. By the law of large numbers, when $n \rightarrow \infty$, we have $\text{Prob}(MS_t^A) \rightarrow E(\lambda_i)$ and $\text{Prob}\left(\left|MS_t^A - E(\lambda_i)\right| < \varepsilon\right) \rightarrow 0$, where ε is any positive number.

Therefore, when $E(\lambda_t) < 1/2$ and n is sufficiently large, $Prob(MS_t^A < \frac{1}{2}) \rightarrow 1$. Intuitively, the case is equivalent to participating in the same lottery for n rounds in which the chance of winning is less than half in each round. When n is large enough, the probability of losing money is 1.

Similarly, when $E(\lambda_t) > 1/2$, $Prob(MS_t^A < \frac{1}{2}) \rightarrow 0$. Therefore,

$$\begin{aligned}
E(\text{Rank Change}) &= Prob(E(\lambda_t) < 1/2) \\
&= Prob\left(\frac{1}{1+\alpha} - \frac{\Delta c_{min,t}}{(1+\alpha)k} < \frac{1}{2}\right) \\
&= Prob\left(\Delta c_{min,t} > \frac{1-\alpha}{2}k\right) \\
&= \frac{\beta - \frac{1-\alpha}{2}k}{2\beta} \text{ (as } \beta \text{ is sufficiently large).}
\end{aligned}$$

Thus,

$$\frac{d(E(\text{Rank Change}))}{dk} < 0.$$

As $\frac{dk}{dIT_t} < 0$,

$$\frac{d(E(\text{Rank Change}))}{dIT_t} > 0.$$

That is, as IT_t increases, we expect to observe more rank changes.

We now examine the change in market concentration as a result of business process replication.

Firm A 's total market share in expectation is

$$E(MS_t^A) = E\left(\frac{1}{n} \sum_{i=1}^n Prob(c_{it}^A < c_{it}^B)\right) = E\left(\frac{1}{n} \sum_{i=1}^n Prob(\Delta c_{it} < 0)\right) = \frac{1}{1+\alpha} - \frac{\Delta c_{min,t}}{(1+\alpha)k}.$$

The expected industry concentration, measure by the Herfindahl Index (HI), is

$$E(HI) = E(MS_A)^2 + E(MS_B)^2 = \frac{1}{(1+\alpha)^2} \left(1 + \alpha^2 - \frac{2(1-\alpha)\Delta c_{min,t}}{k} + \frac{2\Delta c_{min,t}^2}{k^2}\right).$$

Therefore,

$$\frac{d(E(HI))}{dk} = \frac{2(1-\alpha)\Delta c_{min,t}}{k^2} - \frac{4\Delta c_{min,t}^2}{k^3}.$$

Hence when $\Delta c_{min,t} < 0$, $\frac{d(E(HI))}{dk} < 0$ and when $\Delta c_{min,t} > 0$ and $k < \frac{2\Delta c_{min,t}}{1-\alpha}$, $\frac{d(E(HI))}{dk} < 0$. Therefore,

$\frac{d(E(HI))}{dk} < 0$ if $k < \frac{2|\Delta c_{min,t}|}{1-\alpha}$. In other words, $\frac{d(E(HI))}{dIT_t} > 0$ if $IT_t > IT_t^*$, where $IT_t^* = f^{-1}\left(\frac{2|\Delta c_{min,t}|}{1-\alpha}\right)$.

We have the following two propositions:

Proposition 1. The expected amount of rank change is an increasing function of IT intensity:

$$\frac{d(E(\text{Rank Change}))}{dIT_t} > 0.$$

Proposition 2. The expected concentration is an increasing function of IT intensity when IT intensity is

sufficiently large: $\frac{d(E(HI))}{dIT_t} > 0$ when $IT_t > IT_t^*$, where IT_t^* is defined above.

4 Data Sources and Variables

To test our hypotheses, we gather data on industry-level concentration, turbulence, and IT intensity from multiple sources. We classify industries using the North American Industry Classification System (NAICS).

Industry Turbulence and Concentration

We evaluate industry-level turbulence and concentration growth for two outcomes of interest: revenue (sales) and enterprise value (EV). For each measure, the turbulence of an industry of year t is calculated as the average of the absolute value of rank change of all firms in that industry from year $t-1$ to t . We use rank change instead of absolute change because we do not want to include events that affect all firms in an industry uniformly, such as a sudden change in input prices (see, for example, Comin and Phillipon 2005).

We measure the concentration at the industry level with the Herfindahl index (HI), which is calculated by squaring the market share of each firm in the industry and then summing the squares. As EV

can sometimes be negative, we standardize the lowest negative value in each industry to zero to calculate HI. We measure concentration growth of year t as the percentage change in HI from year $t-1$ to t .

Hou and Robinson (2004), note that yearly HI data might be subject to high volatility. To correct for this possibility, we follow their approach and average the data over three years. We report the results of the average in this paper.²

Panel A of Table 1 provides a detailed description of the above variables and our construction of them.

IT Intensity

We obtain data on industry-level IT and non-IT capital from the Bureau of Economic Analysis's (BEA) "Tangible Wealth Survey." These data are available for 63 industry sectors at roughly the three-digit NAICS level from 1987 to 2004.³ IT capital comprises computer hardware computer software. A more appropriate measure than IT capital stock levels is the service flow of IT stock (Jorgenson and Stiroh 2000, Stiroh 2002). Following the approach outlined in Jorgenson and Stiroh (2000), we calculate the service flow for IT and other forms of capital. Throughout the remainder of this paper, we use the phrase "IT capital" as shorthand for "IT capital service flows"; the same is true for "total capital."

Following Stiroh (2002), we use three different measures of IT intensity: IT capital as the percentage of total tangible wealth (i.e., capital stock), IT capital per full-time employee (FTE),⁴ and IT capital as the percentage of nominal industry output. Like Stiroh, we use IT capital as a percentage of total tangible wealth (ITTW) as our primary measure of IT intensity.

² The results are slightly weaker but substantively unchanged when the noisier year-by-year data are used.

³ Although the data before 1997 were originally based on the Standard Industrial Classification (SIC), BEA has converted them to NAICS.

⁴ Data on the number of full-time employees (FTE) from 1998 to 2004 are from Section 6 of the BEA "National Income and Product Accounts Tables." Earlier data on FTEs from BEA are based on SIC. We generate values for NAICS-based industries by taking the percentage change in the employment from the SIC data. Data on industry output are also from BEA and are detailed at Bureau of Economic Analysis (2004).

After calculating ITTW for each industry and year in our dataset, we convert these raw values to z-values for each year. Z-values measure the number of standard deviations from the mean for each industry. We then calculate each industry's mean z-value over this time period. We use these 1987-2004 mean z-values as a continuous measure of each industry's IT intensity. In our analyses below, therefore, each industry has a single IT intensity value.⁵ To arrive at a discrete categorization of industries as either IT-intensive or non IT-intensive, we took as the threshold the median of these 1987-2004 mean z-values.

We summarize the variables for IT intensity and construction method in Panel B of Table 1.

Combining Data

While the BEA reports capital stock information for the Federal Reserve and credit intermediation industries separately, it combines these two industries when reporting the FTE data. In addition, no firms in CompuStat are classified into the Federal Reserve industry. Therefore, we drop the Federal Reserve industry from our capital stock dataset and use the combined FTE data for the credit intermediation industry only. CompuStat also does not contain any firms in the industry 51, "Management of Companies." We therefore drop this industry as well.⁶ Our final dataset thus consists of 61 industries.

5 Empirical Results

This section empirically investigates the effects of rapid IT adoption on the competitive dynamics of US industries. We present two sets of OLS regression results tying IT to industry-level turbulence and concentration growth. We first examine whether IT-intensive industries in general are more turbulent and are concentrating faster than non IT-intensive industries during 1987-2004. We find that IT-intensive industries are consistently more turbulent than non IT-intensive ones during this period, but not concentrating

⁵ We also conduct analyses in which each industry's IT intensity varied from year to year based on its z-value for the year, and in which raw values instead of z-values are used. Results are substantively unchanged from those reported here.

⁶ In addition, BEA combines the hospital and nursing industries when reporting the industry-level GDP. To address this problem, we allocate their total GDP evenly to each industry.

at significantly higher rates. We then take a difference-in-differences approach that relates industries' IT intensities to their pre- vs. post-1996 changes in turbulence and concentration growth. We show that IT intensity is a significant factor in post-1996 changes to industry dynamics captured by these measures. Finally, we discuss robustness checks to evaluate whether our key findings are artifacts of our particular measures, operationalizations, and model specifications.

Turbulence and Concentration Growth in IT-intensive and non IT-intensive Industries

To examine the difference in the turbulence levels and concentration growth rates between IT-intensive and non IT-intensive industries from 1987-2004, we consider the following model:

$$(1) \quad y = \beta_0 + \beta_1 \text{IT} + \beta_2 \# \text{ of firms} + \varepsilon$$

where y is the dependent variable: turbulence or concentration growth in sales or EV. When the outcome of interest is the turbulence, y is measured as the average rank change of sales or enterprise value. When the outcome of interest is the concentration growth, y is measured as the percentage change of the Herfindahl Index. We also include the number of firms for each industry in each period as a control variable. In the case of turbulence, as the number of firms in an industry increases, firms in the industry will have greater potential to change their ranks. Similarly, in the case of concentration, the number of firms indicates the level of competition and may affect the change of the Herfindahl index. Removing this control variable gives stronger results in all models. In all models presented here, standard errors are corrected for heteroskedasticity and to allow for correlation between industries.

As the continuous measure captures the actual magnitude of difference in IT intensities, we focus our discussion on the continuous measure of IT intensity and use a discrete operationalization, based on whether an industry is above or below the median of IT intensity, as a robustness check.

Table 2 reports the turbulence regression results where the average rank change of sales and enterprise value are used as the dependent variable respectively. We also consider specifications in which we drop low-density industries, or outliers for dependent and independent variables. An industry is con-

sidered to be low-density if CompuStat has data for 5 or fewer firms for this industry in at least one year from 1987 to 2004. We consider an industry as an outlier if its value for the dependent or independent variable in any year is more than four standard deviations away from the population mean. Panel C of Table 1 lists low-density and outlier industries. In addition, we consider model specifications that employ industry fixed effects, and in which industries are weighted by the square root of the number of employees.

In all models shown in Table 2, the coefficients for IT intensity and the number of firms are significant at 1% level. The results indicate that IT intensive industries are more turbulent than non IT-intensive ones during 1987-2004.

We then run a similar set of regressions using the percentage change in concentration (as measured by the Herfindahl index) as the dependent variable and report the results in Table 3. None of the specifications shows significantly higher growth in concentration among IT-intensive industries over the period 1987-2004. In fact, in all cases, the coefficient of the IT variable is negative, albeit often statistically insignificant. This result indicates that industry-level IT intensity was *not* positively associated with concentration growth during the years 1987-2004. We now proceed to divide these years into two periods, and compare the turbulence and concentration growth in these two periods.

Turbulence and Concentration Growth Pre- and Post-1996 for IT-intensive and Non IT-intensive Industries

We first consider the appropriate year to use to divide our sample period (1987-2004) into two periods. Chow test results suggest that 1995, 1996, or 1997 could be used as the break year. We find that the year 1996 gives the most notable and economically significant accelerations in both turbulence and concentration growth rates. Thus, in the following analyses, we use 1996 as the break year. (Results are very similar if we use 1995 or 1997 as the break year.)

Visual inspection of data indicates differences in turbulence and concentration growth before and after 1996. Figure 2a plots each industry's average yearly sales turbulence levels over the period 1987-

1996 against the same average for the period 1997-2004. Figure 2b is a parallel graph of the average percentage change in the Herfindahl index of sales during the two time periods. In both graphs, data points above the 45-degree line represent industries in which turbulence or concentration was higher in the more recent period. In both graphs, we observe a similar pattern: the majority of the data points fall above the 45-degree line. This suggests that industries in general are becoming more turbulent and are concentrating faster after 1996.

We first run a paired t-test to examine the mean difference between the two periods for each industry. The paired t-test rejects the null hypothesis that the mean difference between the two periods is zero at the 5% level for both turbulence and concentration. We then use the goodness of fit test to examine whether the number of industries is uniformly distributed above and below the 45 degree line. We can reject the null hypothesis at the 5% level for concentration. However, we cannot reject it for turbulence.

Looking at both figures we see two interesting facts. In Figure 2a, we see that there are a number of firms near the 45 degree line. In Figure 2b, we see both IT-intensive and non IT-intensive firms are close to each other. These observations may suggest that although the mean is above zero, there may be no difference between IT-intensive and non IT-intensive firms. We test this hypothesis using the chi-square test for differences in probabilities. After removing firms within 1% deviation from the 45 degree line, we test to see if the proportion of industries above the 45 degree line industries is equal for both IT-intensive and non IT-intensive industries. The results of the test show that we can reject the null hypothesis at the 10% level. This suggests that the IT-intensive industries do in fact have a higher proportion of industries above the 45 line than non-IT-intensive ones. Table 4 summarizes the results from these tests.

We next turn to examining these patterns in a regression framework, taking a difference-in-difference approach:

$$(2) y = \beta_0 + \beta_1 D96 + \beta_2 IT + \beta_3 D96 \cdot IT + \beta_4 \# \text{ of firms} + \varepsilon$$

where D96 equals 1 if the year is higher than 1996 and 0 otherwise. This model extends equation (1) with additional dummies for the post-break year period and for its interaction with the IT intensity measure.

We first consider turbulence. Table 5 reports the results for sales and enterprise value in Panel A and B respectively. We first estimate models without the IT variable to determine whether there is a general increase in turbulence after 1996. Models 1-4 in the two panels suggest that the post-1996 period is significantly more turbulent for sales but not for EV. We then introduce the IT variable without the interaction term. The results from Models 5-8 suggest that even when we control for the time period, IT-intensive industries are still significantly more turbulent than are non-IT-intensive industries. Finally, we include the interaction term. Consistent with patterns evident in Figure 2a, results from the last three models show that the increase in turbulence after 1996 is more pronounced for IT-intensive industries.

We then conduct a similar analysis for the concentration growth rates and report the results in Table 6. Similar to the turbulence results, industries on average concentrate faster after 1996. Controlling for the time period, the IT variable does not show any significance. The coefficient for the IT variable is negative in all cases. After we add the interaction term, in several instances, the negative coefficient for IT variable becomes significant. This suggests that before 1996, the concentration growth rate for IT-intensive industries was actually below that of non-IT-intensive industries. The coefficient for the interaction term in the weighted models is positive and significant. This indicates that IT-intensive industries concentrated more quickly than did non-IT-intensive ones after 1996.

Robustness Checks

A natural concern is whether our results are a consequence of our choice of metrics and parameters. In unreported regressions, we modify our analyses in several ways to explore the robustness of our findings.

We first discretely categorize industries as IT-intensive or non-IT-intensive based on their relation to the median intensity and repeat the analysis. We obtain similar results.

We also look at other outcomes of interest in addition to sales and enterprise value, such as earnings before interest, taxes, depreciation, and amortization (EBITDA) and total assets. We also employ other operationalizations of the dependent variables for concentration, such as the first difference in the logarithm of the Herfindahl index and the percentage change in the four-firm concentration ratio (C4).

Results are again similar. In addition, as there is no standard definition of IT intensity, we also repeat the analysis for two other measures of IT intensity: IT capital per FTE and IT capital per industry output. The results are consistent with those presented here.

6 Conclusion

Enterprise information technology is increasingly pervasive in American businesses. As a result, firms are able to more rapidly and completely replicate their innovations in business processes, achieving scale without mass. Other types of IT, such as email, knowledge management systems, wikis, and instant messaging allow firms to propagate innovations that are less structured than entire business processes (McAfee 2006). IT makes it possible for better techniques and processes to become rapidly known and adopted throughout the organization.

We show through a formal model how this process can lead to increased turbulence and concentration. In particular, competition becomes increasingly Schumpeterian as innovators are able to leverage their best practices to rapidly gain market share. At the same time, competitors and new entrants have the opportunity to more rapidly leap-frog and displace leading firms. Our model is consistent not only with the increase in productivity growth since the mid-1990s, but also with the higher levels of turbulence. Furthermore, as predicted by our model, concentration levels have also increased in IT-intensive industries, an outcome that is not consistent with other explanations for higher turbulence.

Our research cannot conclusively establish that causality flows unidirectionally from IT investments to changes in industry dynamics, but our analyses of economy-wide data do present evidence of discontinuities in these dynamics beginning at approximately the same time that investments in IT, and particularly enterprise IT, accelerated. Our qualitative case studies of individual firms and competitive dyads provide clear examples of the phenomena we model and illustrate the causal mechanism.

In addition, while our research finds that IT contributes significantly to the increase in firm-level turbulence and industry concentration, this research does not imply that IT is the only source. For instance, Comin and Mulani (2005) show that a shift in the allocation of resources from the development of

general innovations to the development of R&D innovations may also contribute to the increase in firm-level volatility.

While not the final word on these issues, our cases, model and results suggest a research agenda to further explore changing relationships among IT, turbulence and concentration growth in recent years. In particular, we believe that a great deal of fruitful ground exists between the case studies and the economy-wide analyses. For example, future research detailing the competitive impact of IT within a single industry could help clarify the impetus for technology investments, their timing, and their effects.

Further research could also help determine the duration of IT's competitive impact. If IT is in fact a means to embed and replicate business innovations within a firm, if the boundary of the firm remains high, and if the stock of valuable business innovations is not yet depleted, then one might expect to observe a long-term positive relationship between IT intensity and levels of turbulence and concentration growth rather than a transient one.

However, our model does not necessarily predict that these trends will persist indefinitely. Investments in IT and especially EIT are the key drivers in our story; if they tail off, then, all else being equal, so would productivity, turbulence, and concentration growth. Furthermore, the nature of IT itself is multifaceted and evolving. If innovations in business processes become easier to translate across firm boundaries, our model predicts that the variance in returns might decrease rather than increase.

Table 1

Variable definitions and definitions of outliers. In Panel A, we report data sources used to compute industry concentration and turbulence. In Panel B, we report data sources used to compute IT intensity for each industry. Panel C reports definitions of low-density industries, outliers for dependent and independent variables. The data on IT and non-IT capital are available for 63 industries from BEA. Federal Reserve banks and Management of Companies are dropped in all analyses because CompuStat does not have any data on these industries. An industry is considered a low-density industry if CompuStat has data for only five or fewer firms for this industry in at least one year during 1987-2004. The independent variable used in our regressions is the continuous operationalization of IT capital share of tangible wealth (ITTW). The dependent variables for turbulence analyses are average rank change for sales and enterprise value (EV); for concentration growth analyses they are the percentage change in the Herfindahl Index for sales and enterprise value (EV). We consider an industry an outlier if its value is more than four standard deviations away from the industry mean.

Panel A: Industry Concentration and Turbulence

Variable	Source	Computation
Enterprise Value (EV)	CompuStat	Enterprise Value = Market Value (data25 * data199) + Total Debt (data9 + data34) + Preferred Stock (data130) - Cash and Equivalents (data1) (For two financial industries (Credit intermediation and related activities, and Securities, commodity contracts, investments), enterprise value is calculated without cash and equivalents because of savings accounts.)
Revenue (sasles)	CompuStat	Data 12

Panel B: IT Intensity

Variable	Source	Computation
IT Capital	BEA	Created from the BEA “Tangible Wealth Survey” following the approach outlined in Stiroh (2002)
Non-IT Capital	BEA	Created from the BEA “Tangible Wealth Survey” following the approach outlined in Stiroh (2002)
Total Capital	BEA	IT Capital + Non-IT Capital
Full-time Employees (FTE)	BEA	From Section 6 of the BEA “National Income and Product Accounts Tables”
Industry Output	BEA	From “Survey of Current Business” detailed at Bureau of Economic Analysis (2004)

Panel C: Definitions of Low-density Industries and Outliers

Low-density industries: Forestry & Fishing; Transit; Warehousing; Broadcasting; Information Processing; Legal Services

		Outliers
Independent Variable	ITTW	Computer Systems Design and Related Services
Dependent Variables	Average Rank Change for Sales	Computer and Electronic Product Manufacturing Credit Intermediation and Related Activities
	Average Rank Change for EV	Computer and Electronic Product Manufacturing Credit Intermediation and Related Activities
	Percentage Change in Herfindahl Index for Sales	Miscellaneous Health Care
	Percentage Change in Herfindahl Index for EV	None

Table 2

Comparing turbulence levels of IT intensive industries with non IT-intensive industries using continuous operationalization of IT intensity. The sample period is 1987-2004. The dependent variables are average rank change of sales and enterprise value (EV) of industry i from year $t-1$ to year t respectively. Here IT intensity is a continuous variable. We first calculate IT capital share as a percentage of tangible wealth (ITTW) for each industry in each year, and calculate z-values of these figures for each industry by year. We then calculate each industry's mean z-value over this time period. The logarithms of these mean z-values are used as continuous measures for each industry's IT intensity. Model 1 and Model 2 are OLS and other models are weighted least squares using the square root of FTE in each industry in each year as weights. Standard errors are in parenthesis. All regressions allow errors to be correlated across industries and are corrected for heteroskedasticity.

Model	Average Rank Change for Sales				Average Rank Change for EV			
	1	2	3	4	1	2	3	4
IT-intensity	0.55*** (0.17)	0.30*** (0.08)	0.87*** (0.19)	0.92*** (0.15)	0.75*** (0.22)	0.34*** (0.13)	1.02*** (0.23)	0.90*** (0.20)
# of firms	0.041*** (0.002)	0.041*** (0.002)	0.037*** (0.003)	0.033*** (0.002)	0.07*** (0.002)	0.074*** (0.003)	0.064*** (0.003)	0.066*** (0.003)
Weights			yes	yes			yes	yes
Drop Outliers		yes		yes		yes		yes
Drop low-density industries		yes		yes		yes		yes
Observations	1096	936	1096	936	1095	936	1095	936
Number of industries	61	52	61	52	61	52	61	52
R-squared	0.74	0.77	0.83	0.9	0.83	0.84	0.89	0.93

* Significant at the 10-percent level; ** Significant at the 5-percent level; *** Significant at the 1-percent level

Table 3

Comparing concentration growth rate of IT intensive industries with non IT-intensive industries using continuous operationalization of IT intensity. The sample period is 1987-2004. The dependent variables are percentage changes in Herfindahl Index (HI) of sales and enterprise value (EV) of industry i from year $t-1$ to year t respectively. Following Hou and Robinson (2004), we average the HI over 3 years. We first calculate IT capital share as a percentage of tangible wealth (ITTW) for each industry in each year, and calculate z-values of these figures for each industry by year. We then calculate each industry's mean z-value over this time period. The logarithms of these mean z-values are used as continuous measures for each industry's IT intensity. Model 1 and Model 2 are OLS and other models are weighted least squares using the square root of FTE in each industry in each year as weights. Standard errors are in parenthesis. All regressions allow errors to be correlated across industries and are corrected for heteroskedasticity.

Model	Percentage Change in Herfindahl Sales				Percentage Change in Herfindahl Enterprise Value			
	1	2	3	4	1	2	3	4
IT-intensity	-0.179 (0.32)	-0.221 (0.31)	-0.849* (0.47)	-0.944* (0.51)	-0.23 (0.33)	-0.256 (0.30)	-1.238 (0.90)	-1.341 (0.95)
# of firms	0.001 (0.00)	0.003* (0.00)	0.007*** (0.00)	0.009*** (0.00)	0.004 (0.00)	0.006** (0.00)	0.012 (0.01)	0.014 (0.01)
Weights			yes	yes			yes	yes
Drop Outliers		yes				yes		
Drop low-density industries	no	yes	no	yes	no	yes	no	yes
Observations	1098	954	1098	990	1098	972	1098	990
Number of industries	61	53	61	55	61	54	61	55
R-squared	0	0.001	0.014	0.021	0.002	0.005	0.024	0.026

* Significant at the 10-percent level; ** Significant at the 5-percent level; *** Significant at the 1-percent level

Table 4

Examining the differences in turbulence and concentration between 1987-1996 and 1997-2004. We report the results from the following three tests. 1) The paired t-test. The null hypothesis is that the mean difference between the two periods is zero. 2) The goodness of fit test. The null hypothesis is that industries are uniformly distributed across the 45 degree line. 3) The chi-square test. The null hypothesis is that the proportion of industries above the 45 degree line industries is equal for both IT-intensive and non IT-intensive industries.

	Turbulence			Concentration		
	Paired T-test	Goodness of Fit Test	Chi-square Test for Differences in Proportion	Paired T-test	Goodness of Fit	Chi-square Test for Differences in Proportion
Estimated Value	2.909	1.852	-1.941	4.211	12.519	-1.986
5% Critical Value	2.009	3.841	(+/-) 1.960	2.009	3.841	(+/-) 1.960
10% Critical Value	1.676	2.706	(+/-) 1.645	1.676	2.706	(+/-) 1.645
Number of Industries	54	54	17	54	54	48

Table 5

Comparing turbulence levels of IT-intensive industries with non-IT-intensive industries pre- and post-1996 using continuous operationalization of IT intensity. The sample period is 1987-2004. In Panel A, the dependent variable is the average rank change of sales of industry i from year $t-1$ to year t . In Panel B, the dependent variable is average rank change of enterprise value (EV) of industry i from year $t-1$ to year t . Post-1996 dummy equals 1 if $t > 1996$, 0 otherwise. We first calculate 1) IT capital share as a percentage of tangible wealth (ITTW) for each industry in each year and 2) z-values of these figures for each industry by year. We then calculate each industry's mean z-value over this time period. The logarithms of these mean z-values are used as continuous measures for each industry's IT intensity. Model 1, 2, 5, 6, 9 and 10 are OLS, and other models are weighted least squares using the square root of FTE in each industry in each year as weights. Standard errors are in parentheses. All regressions allow errors to be correlated across industries and are corrected for heteroskedasticity.

Panel A: Average Rank Change of Sales

Model	1	2	3	4	5	6	7	8	9	10	11
IT-intensity					0.56***	0.30** *	0.93***		0.28	0.23	0.68***
					(0.17)	(0.08)	(0.15)		(0.24)	(0.18)	(0.25)
Post-1996 dummy	0.97**	0.68***	1.19***	1.13***	0.99**	0.68** *	1.20***	1.13***	1.02**	0.81** *	1.16***
	(0.41)	(0.24)	(0.41)	(0.31)	(0.42)	(0.24)	(0.42)	(0.31)	(0.43)	(0.28)	(0.40)
Post-1996 dummy * IT-intensity									0.66*	0.57**	0.787**
									(0.38)	(0.27)	(0.36)
# of firms	0.042** *	0.041** *	0.034** *	0.055** *	0.041** *	0.04** *	0.033** *	0.055** *	0.041** *	0.04** *	0.032** *
	(0.002)	(0.002)	(0.002)	(0.005)	(0.002)	(0.002)	(0.002)	(0.005)	(0.002)	(0.002)	(0.002)
Weights			yes	yes			yes	yes			yes
Industry fixed effects				yes				yes			
Drop Outliers		yes	yes	yes		yes	yes	yes		yes	yes
Drop low-density industries		yes	yes	yes		yes	yes	yes		yes	yes
Observations	1096	936	936	936	1096	936	936	936	1096	936	936
Number of industries	61	52	52	52	61	52	52	52	61	52	52
R-squared	0.74	0.77	0.9	0.94	0.74	0.77	0.91	0.94	0.74	0.77	0.90

Panel B: Average Rank Change of EV

Model	1	2	3	4	5	6	7	8	9	10	11
IT-intensity					0.76***	0.35***	0.903***		0.35	0.25	0.57*
					(0.22)	(0.128)	(0.20)		(0.28)	(0.25)	(0.29)
Post-1996 dummy	0.55	0.20	.022	-0.38	0.60	0.22	0.25	-0.38	0.64	.041	.021
	(0.42)	(0.30)	(0.56)	(0.51)	(0.42)	(0.30)	(0.57)	(0.511)	(0.44)	(0.36)	(0.55)
Post-1996 dummy * IT-intensity									0.98**	0.83**	1.12**
									(0.44)	(0.39)	(0.44)
# of firms	0.072***	0.075***	0.068***	0.103***	0.07***	0.074***	0.066***	0.103***	0.07***	0.07***	0.07***
	(0.002)	(0.003)	(0.003)	(0.01)	(0.002)	(0.003)	(0.003)	(0.01)	(0.002)	(0.003)	(0.003)
Weights			yes	yes			yes	yes			yes
Industry fixed effects				yes				yes			
Drop Outliers		yes	yes	yes		yes	yes	yes		yes	yes
Drop low-density industries		yes	yes	yes		yes	yes	yes		yes	yes
Observations	1096	936	936	936	1096	936	936	936	1096	936	936
Number of industries	61	52	52	52	61	52	52	52	61	52	52
R-squared	0.83	0.83	0.93	0.96	0.83	0.84	.0.93	0.96	0.74	0.77	0.93

* Significant at the 10-percent level; ** Significant at the 5-percent level; *** Significant at the 1-percent level

Table 6

Comparing concentration growth rate of IT-intensive industries with non-IT-intensive industries pre- and post-1996 using continuous operationalization of IT intensity. The sample period is 1987-2004. In Panel A, the dependent variable is the percentage change in the Herfindahl Index (HI) of sales of industry i from year $t-1$ to year t . In Panel B, the dependent variable is the percentage change in Herfindahl Index (HI) of enterprise value (EV) of industry i from year $t-1$ to year t . Following Hou and Robinson (2004), we average the HI over three years. We first calculate 1) IT capital share as a percentage of tangible wealth (ITTW) for each industry in each year and 2) z-values of these figures for each industry by year. We then calculate each industry's mean z-value over this time period. The logarithms of these mean z-values are used as continuous measures for each industry's IT intensity. Model 1, 2, 5, 6, 9 and 10 are OLS and other models are weighted least squares using the square root of FTE in each industry in each year as weights. Standard errors are in parentheses. All regressions allow errors to be correlated across industries and are corrected for heteroskedasticity.

Panel A: Concentration growth rate of Sales

Model	1	2	3	4	5	6	7	8	9	10	11
IT-intensity					-0.165 (0.32)	-0.207 (0.31)	-0.843 (0.52)		-0.142 (0.42)	-0.576 (0.40)	-1.853*** (0.72)
Post-1996 dummy	4.687*** (0.80)	3.536*** (0.82)	4.347*** (0.89)	4.408*** (0.85)	4.685*** (0.81)	3.534*** (0.82)	4.335*** (0.90)	4.408*** (0.85)	3.938*** (1.00)	3.172*** (0.92)	3.601*** (0.92)
Post-1996 dummy * IT-intensity									-0.025 (0.60)	0.833 (0.57)	2.066** (1.02)
# of firms	0.001 (0.00)	0.002 (0.00)	0.006*** (0.00)	-0.003 (0.01)	0.001 (0.00)	0.002* (0.00)	0.058*** (0.02)	-0.003 (0.01)	0.00 (0.00)	0.00 (0.00)	0.007*** (0.00)
Weights			yes	yes			yes	yes			yes
Industry fixed effects				yes				yes			
Drop Outliers		yes	yes	yes		yes	yes	yes		yes	yes
Drop low-density industries		yes	yes	yes		yes	yes	yes		yes	yes
Observations	1098	954	954	954	1098	954	954	954	1098	954	954
Number of industries	61	53	53	53	61	53	53	53	61	53	53
R-squared	0.039	0.026	0.058	0.136	0.039	0.027	0.008	0.136	0.028	0.023	0.062

Panel B: Concentration growth rate of EV

Model	1	2	3	4	5	6	7	8	9	10	11
IT-intensity					-0.214 (0.33)	-0.238 (0.30)	-1.272 (0.98)		-0.413 (0.28)	-0.422 (0.41)	-2.499** (1.08)
Post-1996 dummy	5.570*** (1.85)	4.686** (1.90)	6.228* (3.33)	6.180* (3.33)	5.567*** (1.86)	4.683** (1.90)	6.210* (3.33)	6.180* (3.33)		4.710** (1.92)	5.772* (3.29)
Post-1996 dummy * IT-intensity										0.452 (0.68)	2.743** (1.28)
# of firms	0.003 (0.00)	0.005* (0.00)	0.011 (0.01)	0.015 (0.02)	0.004 (0.00)	0.005** (0.00)	0.091 (0.10)	0.015 (0.02)	0.006** (0.00)	0.005** (0.00)	0.01 (0.01)
Weights			yes	yes			yes	yes			yes
Industry fixed effects				yes				yes			
Drop Outliers		yes	yes	yes		yes	yes	yes		yes	yes
Drop low-density industries		yes	yes	yes		yes	yes	yes		yes	yes
Observations	1098	972	972	972	1098	972	972	972	990	972	972
Number of industries	61	54	54	54	61	54	54	54	55	54	54
R-squared	0.042	0.036	0.049	0.081	0.042	0.037	0.005	0.081	0.005	0.037	0.056

* Significant at the 10-percent level; ** Significant at the 5-percent level; *** Significant at the 1-percent level

Figure 1

Figure 1a shows annual US corporate investment in Equipment, Plant and IT as percentages of total, Figure 1b, shows U.S. Corporate IT stocks and flows per full-time employee (FTE), and Figure 1c shows the real quantity of computers. In Figure 1a, the three values for each year sum to 100%. In Figure 1b, each year's value is calculated by taking total IT stock (at historical cost) and dividing by total FTEs. (Data source: Bureau of Economic Analysis (BEA) Tangible Wealth Survey and Department of Commerce (BEA), Fixed Assets Table 2.2.)

Figure 1a

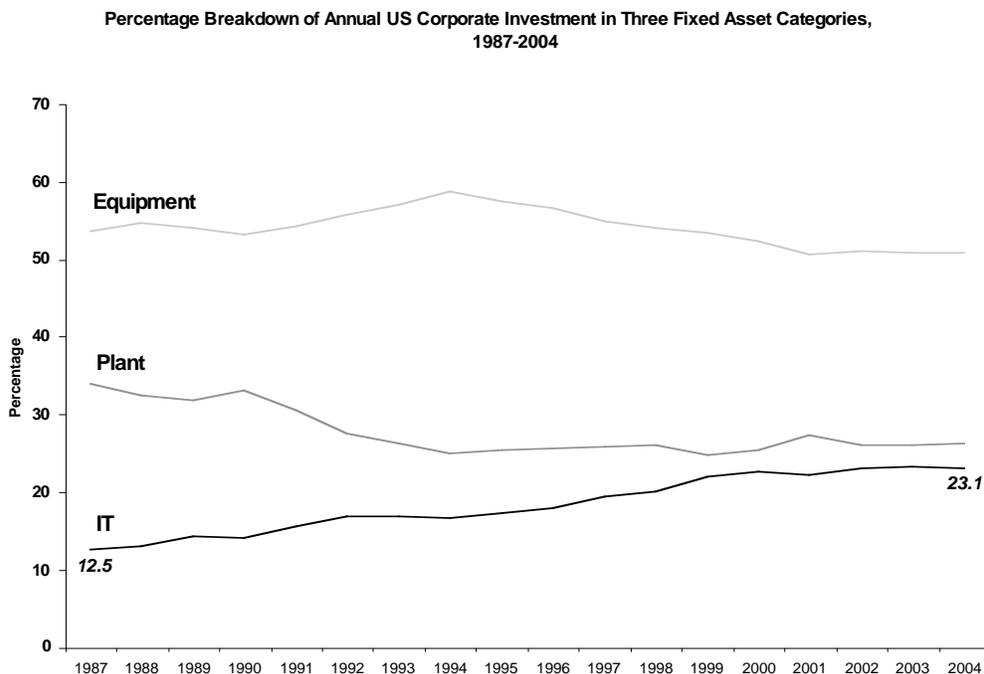


Figure 1b

US Corporate IT Stocks and Flows, 1987-2004

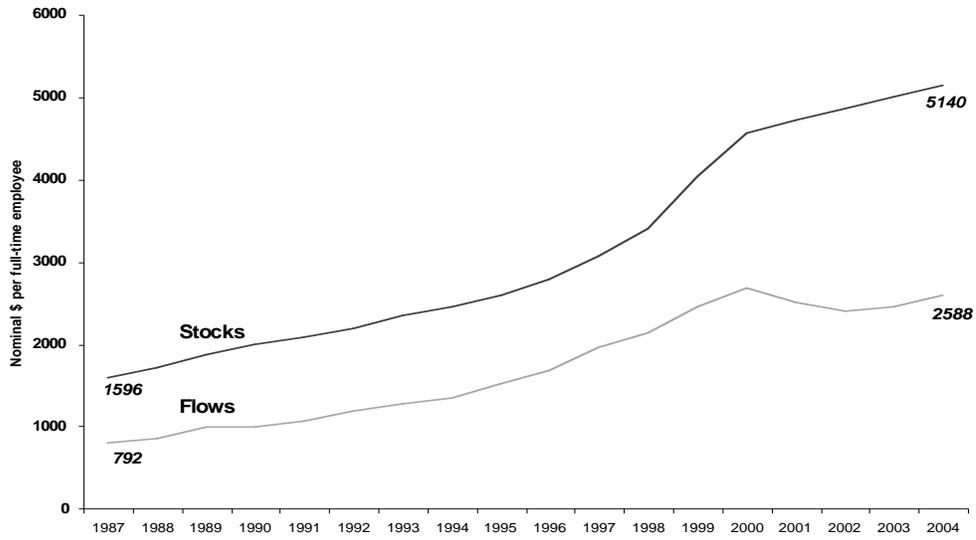


Figure 1c

Real Quantity of Computers, 1987-2005

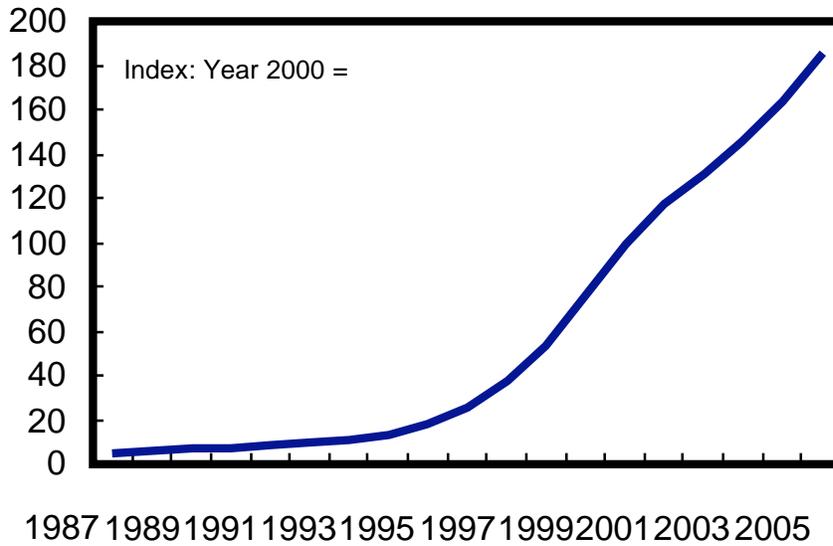


Figure 2

Scatterplot of average yearly changes in sales turbulence and average yearly changes in the Herfindahl Index of sales, 1987-1996 vs. 1997-2004. These graphs contain 55 data points, one for each industry. In Figure 2a, one industry, Computer and electronic product manufacturing, is not shown because plotting its data point – $x = 36.99$, $y = 49.28$ – would compress the rest of the graph. (Data source: CompuStat.)

Figure 2a

Turbulence in sales, 1987-1996 vs. 1997-2004

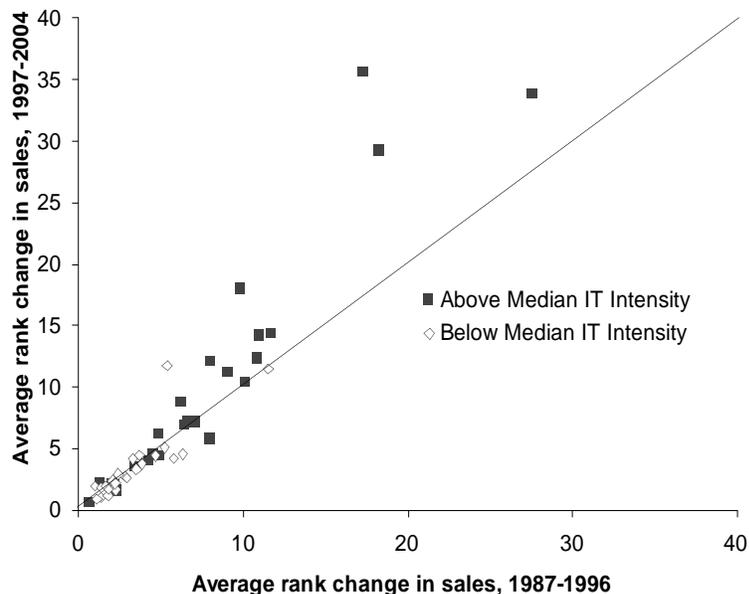


Figure 2b

Average growth rate in HI of Sales 1987-1996 vs. 1997-2004

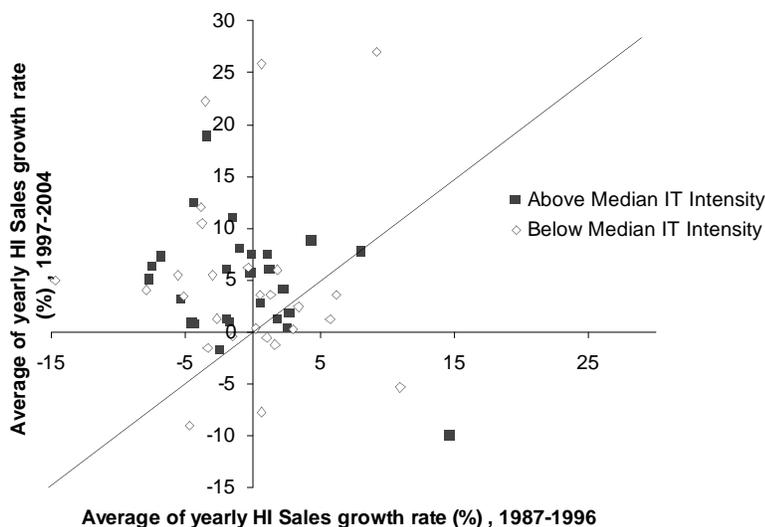
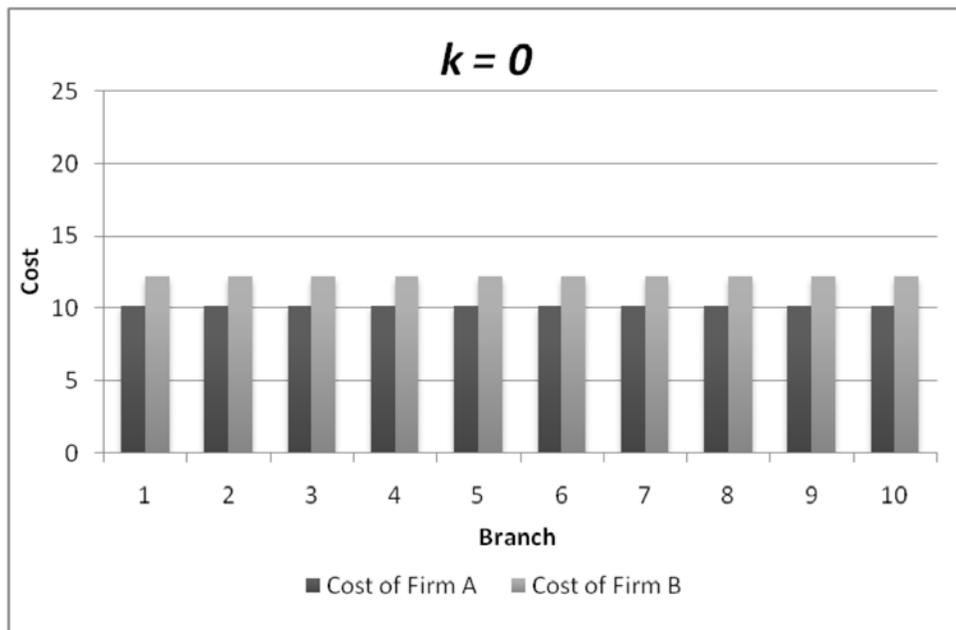
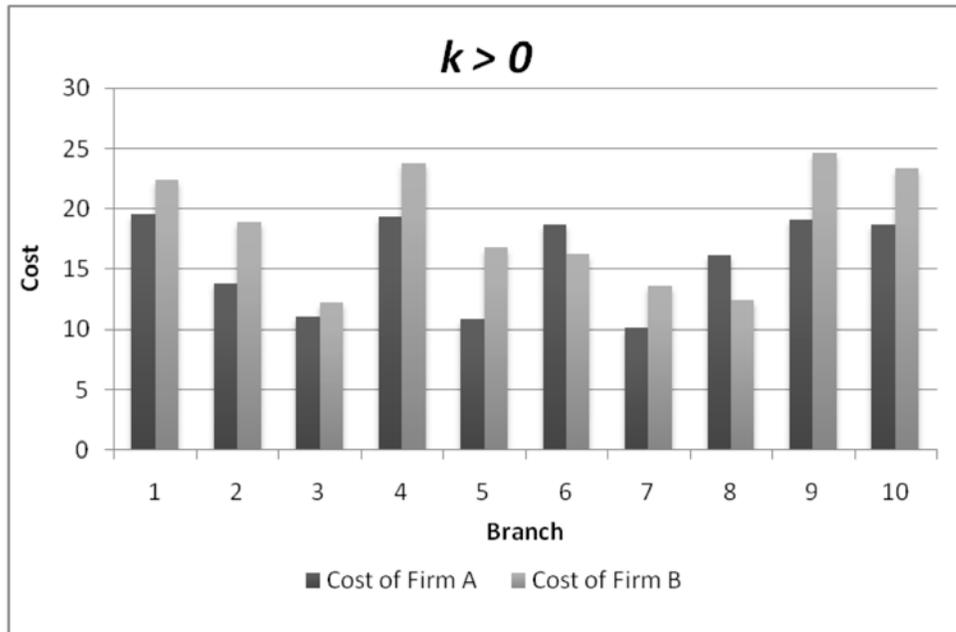


Figure 3

The diagrams illustrate the cost distributions of the two firms for $k > 0$ and $k = 0$. The first diagram illustrates the scenario when $k > 0$, where each firm has cost advantage in several branches. When $k = 0$, both firms replicate their business processes with lowest costs and thus the cost difference between the two firms is the same across all branches. In this example, with perfect replication, firm A has cost advantage in all cities.



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