

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 industry-level changes that have occurred during the same time and argue that they are consistent with an increased use of information technology (IT). We use case studies to illustrate how 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 then empirically document a substantial increase in turbulence starting in the 1990s, as measured by the average intra-industry rank change in sales, earnings before interest, taxes, depreciation and amortization (EBITDA), and other metrics. In particular, we find that IT-intensive industries account for most of this increase in turbulence, especially after 1995. In addition, we find that IT-intensive industries became more concentrated than non IT-intensive industries after 1995, reversing the previous trend. The combination of increased turbulence and concentration, especially among IT-intensive industries, is consistent with recent theories of hypercompetition as well as Schumpeterian creative destruction. We conclude that the improved ability of firms to replicate business innovations has changed the nature of business competition.

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

Introduction

[Figure 1a, 1b and 1c about here.]

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 2006, 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 21% 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 2006, 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).

In this paper, drawing from a series of case studies, we show that contemporary IT, in particular large-scale commercial enterprise applications, 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 rapidly or 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, 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.

We therefore hypothesize that the increased use of IT will increase both turbulence and concentration at the industry level. Using data from Compustat about firm performance and IT data from the Bureau of Economic Analysis (BEA) on industry-level IT investment, we document a substantial increase in turbulence starting in the 1990s, as measured by the average intra-industry rank change in sales, earnings before interest, taxes, depreciation and amortization (EBITDA), and other metrics. In particular, we find that IT-intensive industries account for most of this increase in turbulence, especially after 1995. In addition, we find that IT-intensive industries became more concentrated than non IT-intensive industries after 1995, reversing the previous trend. The combination of increased turbulence and concentration, especially among IT-intensive industries, is consistent with an increasingly Schumpeterian style of creative destruction (Schumpeter, 1939, 1947) as well as more recent theories of hypercompetition.

According to D'Aveni (1994), hypercompetition is an environment with intense and rapid change, in which competitive rules of the game change rapidly, and firms must move quickly to build new advantages and erode the advantages of their rivals. While traditional approaches to strategy emphasize sustainable competitive advantage (e.g., Porter 1985), the hypercompetition perspective suggests that markets today have become inherently unstable as they are fraught with uncertainty, diverse global players and rapid technological changes. As a result, competitive advantage is temporal and can only be obtained by continuous exploitation of short-term opportunities and creative destruction of opponents' advantage. Scholars, however, do not have a consensus on the existence of hypercompetition. For example, Thomas (1996) and Thomas and D'Aveni (2004) find that in the manufacturing sector there is a monotonic shift towards more temporary advantages as well as indicators of increasing market instability. Wiggins and Ruefli (2002, 2005) analyze 40 industries and find that only a very few firms exhibit superior economic performance for a long time frames. In addition, competitive advantage has become harder to sustain and this phenomenon is seen across a broad range of industries. Similar findings

have been reported in Jacobsen (1998), Foster and Kaplan (2001) and Brown and Eisenhardt (1998). In contrast, other recent studies show the opposite (e.g., Mueller, 1986; Odagiri and Yamawaki, 1990; Makadok, 1998; Roberts, 1999; Gimeno and Woo, 2001; Maruyama and Odagiri, 2002; McNamara, Vaaler and Devers, 2003). For example, Makadok (1998) finds that early-movers in the mutual fund industry enjoy both a highly sustainable pricing advantage and a moderately sustainable market share advantage. McNamara et al. (2003) find that while performance and market stability decreased from the later 1970s to the later 1980s, this trend reversed from the later 1980s to the mid-1990s. They argue that the perceptions of increasing instability in current time periods could result from hindsight bias.

Our study provides comprehensive evidence using a dataset covering all public firms in more than 50 industries from 1987 to 2006. Previous studies have either looked at a single industry (e.g., Thomas, 1996; Makadok, 1998) or examine a time period before mid-1990s (e.g., Wiggins and Rue, 2002, 2005; Roberts, 1999). Scholars have noted that hypercompetition is a relatively new phenomenon and has become wide-spread recently (e.g., Bettis and Hitt, 1995; Thomas, 1996). Therefore, it is important to examine recent changes in industry dynamics. Our study shows not only an increase in market instability from 1987 to 2006, but also acceleration of this change after mid-1990s.

Second, our study suggests that the increased use of IT is a key driver of recent shift in industry dynamics and develops a formal model of this mechanism. While technology has been suggested a number of times in the literature as one of the potential contributors to hypercompetition (e.g., Bettis and Hitt, 1995; Grimm, Lee and Smith, 2005), the linkage between IT and these industry dynamics has not to our knowledge been empirically tested. We show that IT intensity of different industries can explain variations in the rate of change in competitive dynamics among these industries.

Third, while the hypercompetition literature typically focuses on increases in industry volatility over time and the resultant lack of sustainable advantage, our study also suggests the emergence of winner-takes-all dynamics as a result of the improved ability to replicate best business practices. Hence, while competitive advantage becomes more difficult to maintain, it is also more rewarding. In addition, as

our case studies demonstrate, such winner-takes-all dynamics do not require radical innovation—small innovation widely replicated can have dramatic impacts on industry dynamics.

Our study also contributes to the stream of economics research on the impact of IT. A key finding from past research 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, 2003; Stiroh, 2002). 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, Brynjolfsson and Hitt, 2002) and the outcomes linked to them, including productivity and revenue gains (Dedrick et al., 2003; Brunner et al., 2006), stock market valuations (Brynjolfsson, Hitt and Yang, 2002; Im, Dow and Grover, 2001), levels of vertical integration and diversification (Hitt, 1999; Dewan, Michael and Min, 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 industries 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 competitive advantage (Mata, Fuerst and Barney, 1995; Powell and Dent-Micallef, 1997; Prahalad and Krishnan, 2002; Medina-Garrido, Ruiz-Navarro and Bruque-Camara, 2005) 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 or surveys of a small number of firms. Accordingly, this paper extends research on the impact of IT by statistically assessing outcomes related to competition.

Finally, our study is related to the literature on replication. Replication is a process of reproducing a successful routine in new settings (Winter and Szulanski, 2001; Baden-Fuller and Winter, 2007). Scholars have shown that the ability to replicate best practices internally is critical to a firm's

performance (Szulanski, 1996; Dagnino, 2005; Szulanski and Jensen, 2006). In addition, successful replication is shown to hinge on efficient codification of a successful routine into a template (Nelson and Winter, 1982; Zander and Kogut, 1995; Jensen and Szulanski, 2007). Our research, using a series of case studies, finds that IT, particularly enterprise information technology (EIT) post mid-1990s, could substantially increase the speed and fidelity of replication using templates. We argue that this improved replication ability as a result of IT usage not only affects individual firms' productivity, as shown in many previous studies (e.g., Szulanski and Jensen, 2006), but also leads to winner-takes-all dynamics.

This rest of the paper is organized as follows. In the next section, we use several short case examples to describe how contemporary IT is used to embed and replicate business innovations, and why this process could be expected to lead to competitive heterogeneity across firms in an industry. Given these empirical observations, we then present our hypotheses. Next we describe our data sources and variables, and present results of empirical analyses that make use of industry-level IT endowment and firm-level performance data. Finally we provide a brief summary and conclusion. In the appendix, we provide a simple analytical model of competition that formalizes how, over time, both concentration and turbulence will increase as IT-enabled replication becomes more prevalent.

IT and Business Process Replication

The ability to replicate best practices within a firm is critical to building competitive advantage. However, process replication has traditionally been 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 of software firms are consequences 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 industry 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 in “bricks and mortar” industries. 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 the precise 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.

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

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 at the industry level 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 and the Internet, 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 EIT initiative is far from guaranteed (see, for example, McAfee, 2003; 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, Qasimi and Ooms-Wallis, 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, Dessain and Sjoman, 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.' As Winter and Szulanski (2001) point out, companies in more than 60 industries are actively pursuing replication strategy today.

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, 2007) and highlights the importance of complementarities in explaining the difficulty of diffusion (Ichniowski, Shaw and Prennushi, 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, Fitoussi and Hitt, 2005). Merely buying the same customer relationship management system as Wal-Mart, for example, 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.

The idea that innovation is difficult to propagate across firms is also consistent with the literature on new growth theory (Romer 1990, 1994). 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. 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 case below illustrates the difficulties of inter-firm transfer of IT-enabled business processes and suggests that knowledge continued to be excludable even after it’s embedded in technology.

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 significantly 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).

Monopolies are not Eternal

As firms continue to invest in IT to embed and diffuse knowledge, competition today becomes more knowledge-based. 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-takes-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).

[Figure 2a and 2b about here.]

We develop a formal model of how this process can change the nature of competition, changing the specific metrics we study. While the details of this model are provided in the Appendix, the basic insights can be understood by examining Figure 2a and 2b which illustrate how the improved ability to replicate business processes, or transfer knowledge, can lead to more winner-takes-all dynamics. Consider an industry with two competing firms, A and B. Assume that the economy has 10 distinct locations or ‘cities’ and each firm has one branch in every city. Each branch tries to innovate and comes up with its own business process. Assume that different business processes lead to different production costs. In each city, the branch with the lower cost wins the market (i.e., it has 100% market share in this city). Consider the scenario that replication is not possible or cannot be done perfectly. As shown in Figure 2a, some branches of firm A come up with better business processes that lead to lower costs. In this case, firm A wins the markets in 6 cities but loses the markets in other 4 cities. Assuming that all cities have homogeneous demand, firm A obtains 60% market share. With perfect replication, as shown in Figure 2b, each firm replicates its business process with the lowest cost across its branches. Thus the cost difference between the two firms is the same in all cities. In this case, firm A’s lowest cost (from the process of its

branch in city 1) is higher than firm B's (from the process of its branch in city 9). As a result, firm B wins the market in every city and becomes a monopoly in this industry.

Monopolies are not eternal, however. Competitive equilibria are repeatedly disturbed by new 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). We can anticipate 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 discussion in the previous section provides three stylized facts. First, contemporaneous IT, such as EIT and the Internet, which became widely adopted after mid-1990s, substantially increased ease, speed, and fidelity of intra-firm business process replication. Second, boundary of firm remains important. Processes replicated within firms are difficult to be imitated by their rivals instantly. Third, as business innovation continues, a firm's best practice today might not be the best practice tomorrow. Competitors and new entrants can also innovate and create best practices.

Our broad hypothesis is that the combination of these forces led to more Schumpeterian competition and heightened winner-take-all dynamics in the economy. 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.

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).

[Table 1 about here.]

Industry Turbulence and Concentration

We evaluate industry-level turbulence and concentration growth for two outcomes of interest: revenue (sales) and EBITDA using firm-level data from Compustat. EBITDA is often used to analyze firm profitability as it eliminates the effects of financing and accounting decisions. 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. It also helps mitigate the impact of outliers on our results. Rank change has been used in a number of other studies to measure industry turbulence (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 EBITDA 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 (2006) note that industry-level measures computed from Compustat firm-level data might be subject to high volatility. To correct for this possibility, we follow their approach and use

the mean of average rank change and HI over three years. We report the results of the average in this paper.²

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 2006.³ 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 as our primary measure of IT intensity.

Table 1 provides the data sources of above variables.

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

² The results are 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).

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 “Management of Companies.” We therefore drop this industry as well.⁵ Our final dataset thus consists of 61 industries.

Empirical Results

This section empirically investigates the effects of rapid IT adoption on the competitive dynamics of US industries. We present two sets of regression results tying IT to industry-level turbulence and concentration growth. We first examine whether industries that are IT-intensive in general are more turbulent and are concentrating faster than non IT-intensive industries during 1987-2006. We find that IT-intensive industries are consistently more turbulent than non IT-intensive ones during this period, but not concentrating at significantly higher rates. We then take a difference-in-differences approach that relates industries’ IT intensities to their pre- vs. post-1995 changes in turbulence and concentration growth. We show that IT intensity is a significant factor in post-1995 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 1987-2006, we consider the following model:

$$(1) \quad y = \beta_0 + \beta_1 IT + \beta_2 N + \varepsilon$$

where y is the dependent variable: turbulence or concentration growth in sales or EBITDA. When the outcome of interest is the turbulence, y is measured as the average rank change of sales or EBITDA. When the outcome of interest is the concentration growth, y is measured as the percentage change of the Herfindahl Index. IT is the level of information technology capital intensity in the industry. We also

⁵ 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.

include the number of firms for each industry in each period, N , 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 are allowed for correlation between industries.

[Table 2 about here.]

[Table 3 about here.]

Table 3 reports the turbulence regression results where the average rank change of sales and EBITDA are used as the dependent variable respectively. To ensure that our results are not driven by outliers and industries with smaller number of firms, we also consider specifications in which we drop outliers for dependent and independent variables, and low-density industries. We consider an industry as an outlier if its value for the dependent or independent variable in any year is more than 6 standard deviations away from the population mean. IT intensive industries such as “Computer Systems Design and Related Services” and “Information and Data Processing Services” are thus dropped. An industry is considered to be low-density if Compustat has data for 10 or fewer firms for this industry in at least one year from 1987 to 2006. Table 2 lists outlier and low-density industries. We are also concerned that due to wide variation of industry size, these unweighted regressions allow small industries to have equal impact on the results as big industries. As suggested in Kahn and Lim (1998) and Stiroh (2002), weighted least squares specifications are more appropriate because the variance of error terms is inversely related to industry size, most likely due to noisier data in smaller industries. We thus use weighted least squares in Model 3 and 4, using the square root of the number of full-time employees (FTE) as weights (we multiply the independent and dependent variables by the square root of FTE).

In all models shown in Table 3, 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 1987-2006.

[Table 4 about here.]

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 4. Only a few of the specifications shows significantly higher growth in concentration among IT-intensive industries over the period 1987-2006. This result indicates that industry-level IT intensity was *not* strongly associated with concentration growth during the period 1987-2006. 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-1995 for IT-intensive and Non IT-intensive Industries

We first consider the appropriate year to use to divide our sample period (1987-2006) into two periods. We use year 1995 for a couple of reasons. First, while our discussion of process replication focuses on competitive dynamics, one would expect with improved ability to replicate, firms could substantially improve their productivity as well. Stiroh (2002) shows that the growth of industry productivity accelerates post 1995 and such acceleration is linked to IT usage. Naturally we expect 1995 to be a break year where we observe shifts in competitive dynamics.

Second, both enterprise systems and the Internet became widely adopted around mid-1990s. As the adoption of such systems is closely linked to firms' improved ability in replication, mid-1990s becomes a period during which industry dynamics are likely to shift.

Indeed, analysis of our data using Chow test suggests that 1995, 1996, or 1997 could be used as the break year. Thus, in the following analyses, we use 1995 as the break year, which is consistent with

the literature on the post-1995 American productivity revival (e.g., Stiroh, 2002). Results are very similar if we use 1996 or 1997 as the break year.

[Figure 3a and 3b about here.]

Visual inspection of data indicates differences in turbulence and concentration growth before and after 1995. Figure 3a plots the average sales rank change of all industries over time. It shows that on average, industries become substantially more turbulent after 1995. Figure 3b plots the average concentration growth rate of all industries. We find that industries become less concentrated through the early 1990s. Concentration drops at the fastest rate in year 1995. After 1995, the trend reverses and after 1997, average industry concentration actually increases. It is interesting to observe that both turbulence and concentration growth rates decrease in early 2000s and increase afterwards. This pattern coincides with the changes in IT flows during the same period, as shown in Figure 1b.

[Figure 4a and 4b about here.]

Figure 4a plots each industry's average yearly sales turbulence levels over the period 1987-1995 against the same average for the period 1996-2006. Figure 4b 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 1995. We also compute each industry's average IT-intensity over 1987-2006 and consider those whose average IT intensity is above the median of all industry averages as IT-intensive industries and the rest as non-IT intensive industries. We then label each data point according to their IT intensities. We find IT-intensive industries locate disproportionately above the 45-degree line, suggesting that IT intensive industries become more turbulent or concentrate faster than non-IT intensive ones after 1995. The patterns are similar for EBITDA.

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

$$(2) y = \beta_0 + \beta_1 D95 + \beta_2 IT + \beta_3 D95 \cdot IT + \beta_4 N + \varepsilon$$

where $D95$ equals 1 if the year is higher than 1995 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.

[Table 5 about here.]

We first consider turbulence. Table 5 reports the results for sales and EBITDA 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 1995. Models 1-3 in the two panels suggest that the post-1995 period is significantly more turbulent for sales but not for EBITDA. We then introduce the IT variable without the interaction term. The results from Models 4-6 suggest that even when we control for the time period, IT-intensive industries are significantly more turbulent than are non-IT-intensive industries for both sales and EBITDA. Finally, we include the interaction term. Consistent with patterns evident in Figure 4a, results from the last three models show that the increase in turbulence after 1995 is more pronounced for IT-intensive industries.

[Table 6 about here.]

We then conduct a similar analysis for the concentration growth rates and report the results in Table 6. Models 1-6 suggest that industries on average concentrate faster after 1995 with or without controlling for IT intensity. We then add the interaction term. The post-1995 dummy remains to be significant. In addition, the interaction variable in all specifications except Model 7 in the case of sales, is significantly positive. This result indicates that IT-intensive industries concentrated more quickly than did non-IT-intensive ones after 1995.

Overall, our empirical results support the four hypotheses we developed.

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 look at other outcomes of interest in addition to sales and EBITDA, such as enterprise value 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.

Conclusion

Information technology, in particular EIT and the Internet usage, 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; Wagner and Majchrzak, 2007). IT makes it possible for better techniques and processes to become rapidly known and adopted throughout the organization.

We show how this process can lead to increased turbulence and concentration. In particular, there is increasing evidence of hypercompetition 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 theory of IT-enabled business process replication 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 theory, concentration levels have also increased in IT-intensive industries, an outcome that is not consistent with other explanations for higher turbulence.

Managerial Implications

Our findings have several important implications for managers. While our results are consistent with the idea that we have entered an “age of temporary advantage”, they also underscore the potential for firms to benefit more rapidly from innovations. By quickly replicating new processes via IT, firms can gain market share and even create “winner-take-all” dynamics. This ability to replicate, or leverage, new ideas, can actually increase the value of innovations, both large and small. Companies will want to adjust their recruiting, retention and incentive systems as a result, with a focus on attracting and retaining innovative personnel and motivating them to develop and share new ideas. Ideas which can be embodied or enhanced by technology are likely to have especially high returns. At the same time, because competitors must also be expected to innovate and propagate, managers must assume that any advantage they gain will be temporary. This underscores the need to design for agility, with flexible structures, both internally and externally. Nimble firms are likely to benefit the most in the new competitive environment. Last, but not least, investments in technologies that encourage, aggregate, codify or replicate innovations will make it more likely that a firm can outpace its competitors. In the 1990s, these included enterprise resource planning (ERP) systems, supply chain management (SCM) systems, customer relationship management (CRM) systems and related enterprise technologies, but looking forward, they are likely to be enterprise technologies for collaboration, social networking and business intelligence.

Limitation and Future Research

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 analyze and illustrate a plausible 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, as suggested by many scholars (e.g., D'Aveni, 1994; Brown and Eisenhardt, 1998; Thomas and D'Aveni, 2004; Grimm et al., 2005), hypercompetition is caused by more than just IT. Globalization, shifts in merger and acquisition (M&A) activity, more fragmented customer tastes, and deregulation could all contribute to the hypercompetitive shift. On the other hand, several previous studies suggest that the patterns documented in our study are not primarily driven by globalization and shifts in M&A activity. Ghemawat (2006) finds that industry concentration tends to decrease as globalization rises, implying that the increase of concentration after mid-1990s is not because of more global competition. White (2002) contends that M&A activity explained neither the decline in concentration in the first half of the 1990s nor its rise in the second half.

While not the final word on these issues, our cases and empirical 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 hypotheses do not necessarily predict that these trends will persist indefinitely. Investments in IT are the key drivers in our story; if they tail off or change qualitatively 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.

Appendix

We use a stylized model to illustrate the impact of information technology on firm performance and industry dynamics. 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 2a corresponds to the scenario where $k > 0$ and Figure 2b corresponds to the scenario where $k = 0$. 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

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

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 $\text{Prob}(|MS_t^A - E(\lambda_i)| < \varepsilon) \rightarrow 1$, where ε is any positive number.

Therefore, when $E(\lambda_i) < 1/2$ and n is sufficiently large, $Prob(MS_i^A < \frac{1}{2}) \rightarrow 1$. 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 $E(\lambda_i) > 1/2$, $Prob(MS_i^A < \frac{1}{2}) \rightarrow 0$. Therefore,

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

Thus,

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

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

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

That is, as IT_i 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

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

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.

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Table 1: Data sources

We report data sources used to compute industry concentration and turbulence, and IT intensity.

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

Table 2: List of outlier and low-density industries

We list outliers for dependent and independent variables, and low-density industries. We consider an industry an outlier if for a given variable, its value is more than 6 standard deviations away from the industry mean. An industry is considered a low-density industry if Compustat has data for only 10 or fewer firms for this industry in at least one year during 1987-2006.

		Outliers
Independent Variable	IT Intensity	Computer Systems Design and Related Services Information and Data Processing Services Securities, Commodity Contracts, Investments
Dependent Variables	Average Rank Change for Sales	Computer and Electronic Product Manufacturing Credit Intermediation and Related Activities
	Average Rank Change for EBITDA	Computer and Electronic Product Manufacturing Credit Intermediation and Related Activities
	Growth in Herfindahl Index for Sales	None
	Growth in Herfindahl Index for EBITDA	None

Low-density industries: Forestry and Fishing; Transit; Warehousing; Broadcasting; Information Processing; Legal Services; Miscellaneous Health Care and Social Assistance

Table 3: Relationship between industry turbulence and IT intensity

The dependent variables are average rank changes of sales and EBITDA of industry i from year $t-1$ to year t respectively. Model 1 and Model 2 employ OLS and Model 3 and 4 employ weighted least squares using the square root of FTE in each industry in each year as weights. All regressions allow errors to be correlated across industries. Heteroskedastic-adjusted standard errors are in brackets.

Model	Average Rank Change of Sales				Average Rank Change of EBITDA			
	1	2	3	4	1	2	3	4
IT-intensity	0.49*** [0.12]	0.26*** [0.07]	0.62*** [0.14]	0.59*** [0.14]	0.77*** [0.15]	0.51*** [0.14]	0.75*** [0.13]	0.72*** [0.19]
# of firms	0.04*** [0.00]	0.04*** [0.00]	0.03*** [0.00]	0.03*** [0.00]	0.07*** [0.00]	0.07*** [0.00]	0.06*** [0.00]	0.06*** [0.00]
Weights			yes	yes			yes	yes
Drop outliers and low-density industries		yes		yes		yes		yes
Observations	1154	950	1154	950	1154	950	1154	950
Number of industries	61	50	61	50	61	50	61	50
R-squared	0.84	0.82	0.92	0.94	0.82	0.78	0.94	0.96

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

Table 4: Relationship between growth of industry concentration and IT intensity

The dependent variables are percentage changes in Herfindahl Index (HI) of sales and EBITDA of industry i from year $t-1$ to year t respectively. Model 1 and Model 2 employ OLS and Model 3 and 4 employ weighted least squares using the square root of FTE in each industry in each year as weights. All regressions allow errors to be correlated across industries. Heteroskedastic-adjusted standard errors are in brackets.

Model	Percentage Change in HI of Sales				Percentage Change in HI of EBITDA			
	1	2	3	4	1	2	3	4
IT-intensity	0.01** [0.01]	0.01*** [0.00]	0.00 [0.01]	0.00 [0.01]	0.06 [0.04]	0.02* [0.01]	0.02 [0.02]	0.01 [0.01]
# of firms	-0.00*** [0.00]	-0.00*** [0.00]	0.00 [0.00]	0.00 [0.00]	0.00 [0.00]	0.00 [0.00]	0.00 [0.00]	0.00 [0.00]
Weights			yes	yes			yes	yes
Drop outliers and low-density industries		yes		yes		yes		yes
Observations	1154	988	1154	988	1154	988	1154	988
Number of industries	61	52	61	52	61	52	61	52
R-squared	0.01	0.02	0.00	0.00	0.01	0.01	0.02	0.04

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

Table 5: Differences-in-differences estimation of the relationship between industry turbulence and IT intensity pre- and post-1995

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 EBITDA of industry i from year $t-1$ to year t . Post-1995 dummy equals 1 if $t > 1995$, 0 otherwise. Model 3, 6 and 9 employ weighted least squares using the square root of FTE in each industry in each year as weights. The rest models use OLS. All regressions allow errors to be correlated across industries. Heteroskedastic-adjusted standard errors are in brackets.

Panel A: Average Rank Change of Sales

Model	1	2	3	4	5	6	7	8	9
IT-intensity				0.43*** [0.13]	0.20*** [0.08]	0.49*** [0.15]	0.15 [0.15]	-0.04 [0.10]	0.14 [0.18]
Post-1995 dummy	0.88*** [0.24]	0.78*** [0.21]	1.34*** [0.33]	0.75*** [0.26]	0.69*** [0.17]	1.22*** [0.35]	0.74*** [0.25]	0.78*** [0.23]	1.25*** [0.36]
Post-1995 dummy * IT-intensity							0.86*** [0.25]	0.74*** [0.17]	0.89*** [0.24]
# of firms	0.04*** [0.00]	0.04*** [0.00]	0.03*** [0.00]	0.04*** [0.00]	0.04*** [0.00]	0.03*** [0.00]	0.04*** [0.00]	0.04*** [0.00]	0.03*** [0.00]
Weights			yes			yes			yes
Drop outliers and low-density industries		yes	yes		yes	yes		yes	yes
Observations	1154	950	950	1154	950	950	1154	950	950
Number of industries	61	50	50	61	50	50	61	50	50
R-squared	0.84	0.83	0.94	0.84	0.91	0.94	0.84	0.83	0.94

Panel B: Average Rank Change of EBITDA

Model	1	2	3	4	5	6	7	8	9
IT-intensity				0.78***	0.37***	0.77***	0.53***	0.18	0.34*
				[0.15]	[0.14]	[0.19]	[0.16]	[0.15]	[0.20]
Post-1995 dummy	0.08	0.26	-0.40	-0.16	0.47*	-0.59	-0.17	0.19	-0.55
	[0.30]	[0.26]	[0.38]	[0.29]	[0.25]	[0.41]	[0.29]	[0.27]	[0.42]
Post-1995 dummy * IT-intensity							0.78***	1.05***	1.09***
							[0.27]	[0.29]	[0.34]
# of firms	0.08***	0.07***	0.06***	0.07***	0.07***	0.06***	0.07***	0.07***	0.06***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Weights			yes			yes			yes
Drop outliers and low-density industries		yes	yes		yes	yes		yes	yes
Observations	1154	950	950	1154	950	950	1154	950	950
Number of industries	61	50	50	61	50	50	61	50	50
R-squared	0.82	0.78	0.95	0.82	0.88	0.96	0.82	0.79	0.96

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

Table 6: Differences-in-differences estimation of the relationship between concentration growth and IT intensity pre- and post-1995

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 EBITDA of industry i from year $t-1$ to year t . Post-1995 dummy equals 1 if $t > 1995$, 0 otherwise. Model 3, 6 and 9 employ weighted least squares using the square root of FTE in each industry in each year as weights. The rest models use OLS. All regressions allow errors to be correlated across industries. Heteroskedastic-adjusted standard errors are in brackets.

Panel A: Concentration growth rate of Sales

Model	1	2	3	4	5	6	7	8	9
IT-intensity				0.01 [0.01]	0.01** [0.00]	0.00 [0.01]	0.00 [0.01]	0.00 [0.00]	-0.01 [0.01]
Post-1995 dummy	0.06*** [0.01]	0.04*** [0.01]	0.04*** [0.01]	0.05*** [0.01]	0.04*** [0.01]	0.04*** [0.01]	0.05*** [0.01]	0.04*** [0.01]	0.04*** [0.01]
Post-1995 dummy * IT-intensity							0.02 [0.01]	0.02*** [0.01]	0.02** [0.01]
# of firms	-0.00*** [0.00]	-0.00*** [0.00]	0.00 [0.00]	-0.00*** [0.00]	-0.00*** [0.00]	0.00 [0.00]	-0.00*** [0.00]	-0.00*** [0.00]	0.00 [0.00]
Weights			yes			yes			yes
Drop outliers and low-density industries		yes	yes		yes	yes		yes	yes
Observations	1154	988	988	1154	988	988	1154	988	988
Number of industries	61	52	52	61	52	52	61	52	52
R-squared	0.04	0.05	0.04	0.05	0.06	0.04	0.05	0.06	0.05

Panel B: Concentration growth rate of EBITDA

Model	1	2	3	4	5	6	7	8	9
IT-intensity				0.05	0.01	0.00	0.00	0.00	-0.02
				[0.04]	[0.01]	[0.02]	[0.05]	[0.01]	[0.02]
Post-1995 dummy	0.12**	0.06*	0.09*	0.10*	0.06***	0.09*	0.10*	0.05*	0.09*
	[0.06]	[0.03]	[0.05]	[0.06]	[0.02]	[0.05]	[0.05]	[0.03]	[0.05]
Post-1995 dummy * IT-intensity							0.16**	0.04**	0.05*
							[0.08]	[0.02]	[0.03]
# of firms	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Weights			yes			yes			yes
Drop outliers and low-density industries		yes	yes		yes	yes		yes	yes
Observations	1154	988	988	1154	988	988	1154	988	988
Number of industries	61	52	52	61	52	52	61	52	52
R-squared	0.01	0.02	0.07	0.01	0.05	0.07	0.02	0.02	0.08

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

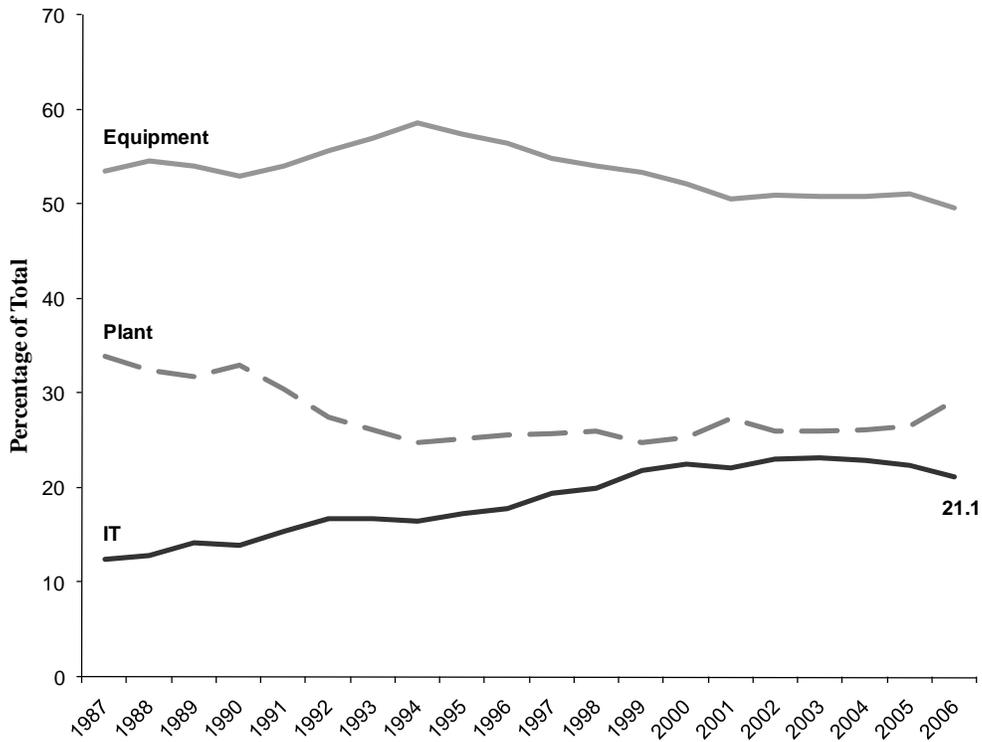


Figure 1a: Percentage breakdown of annual US corporate investment in three fixed asset categories as a percentage of total, 1987-2006 (Data source: Bureau of Economic Analysis (BEA) Tangible Wealth Survey)

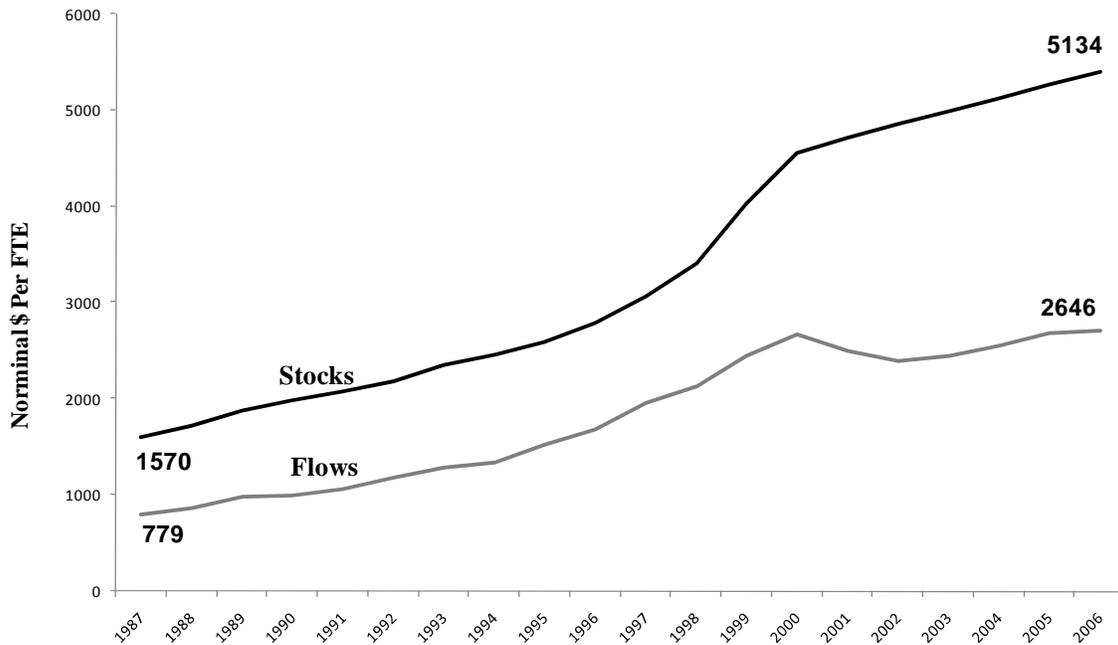


Figure 1b: U.S. corporate IT stocks and flows per full-time employee (FTE), 1987-2006
 (Data source: Bureau of Economic Analysis (BEA) Tangible Wealth Survey and Fixed Assets Table 2.2.)

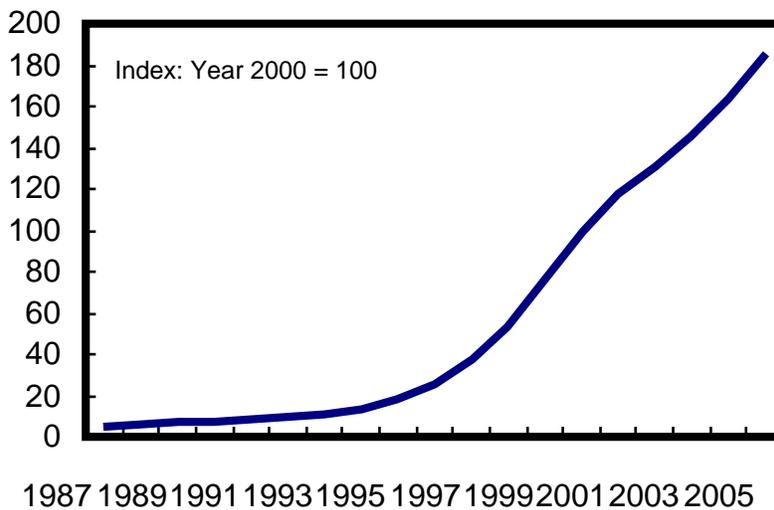


Figure 1c: Real quantity of computers, 1987-2005

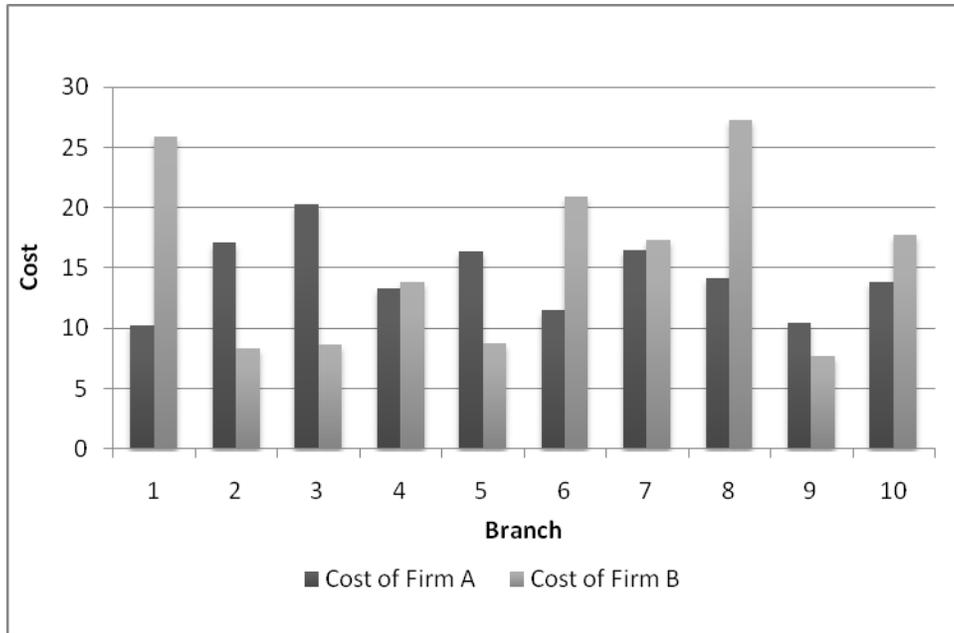


Figure 2a: Cost distribution of firm A and B without perfect replication

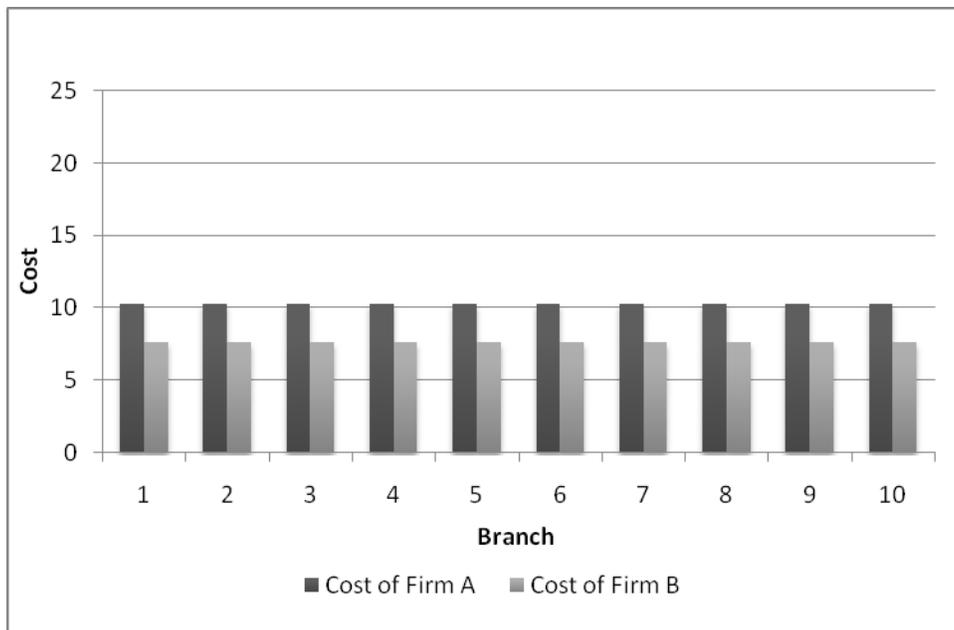


Figure 2b: Cost distribution of Firm A and B with perfect replication

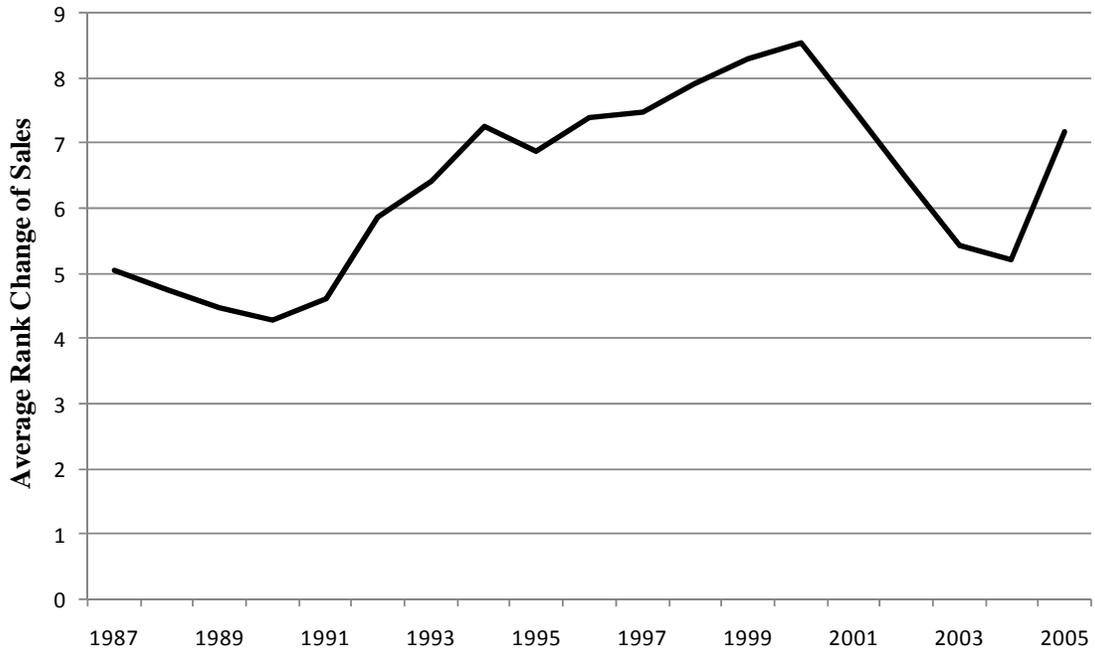


Figure 3a: Average sales rank change over time

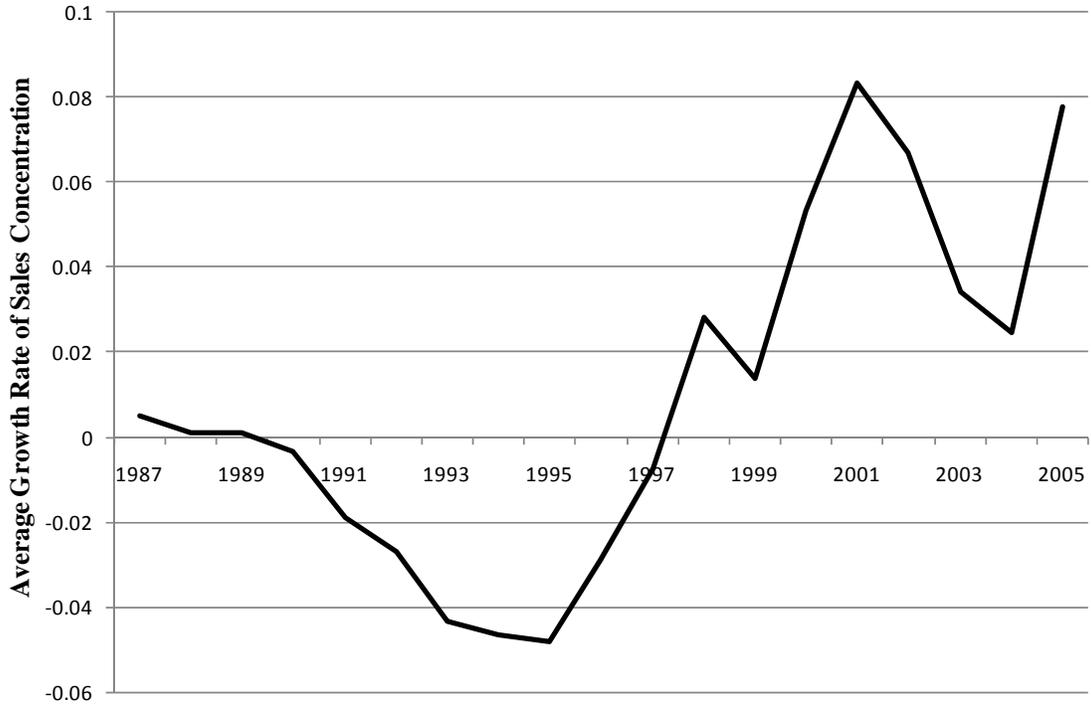


Figure 3b: Average growth rate of sales concentration over time

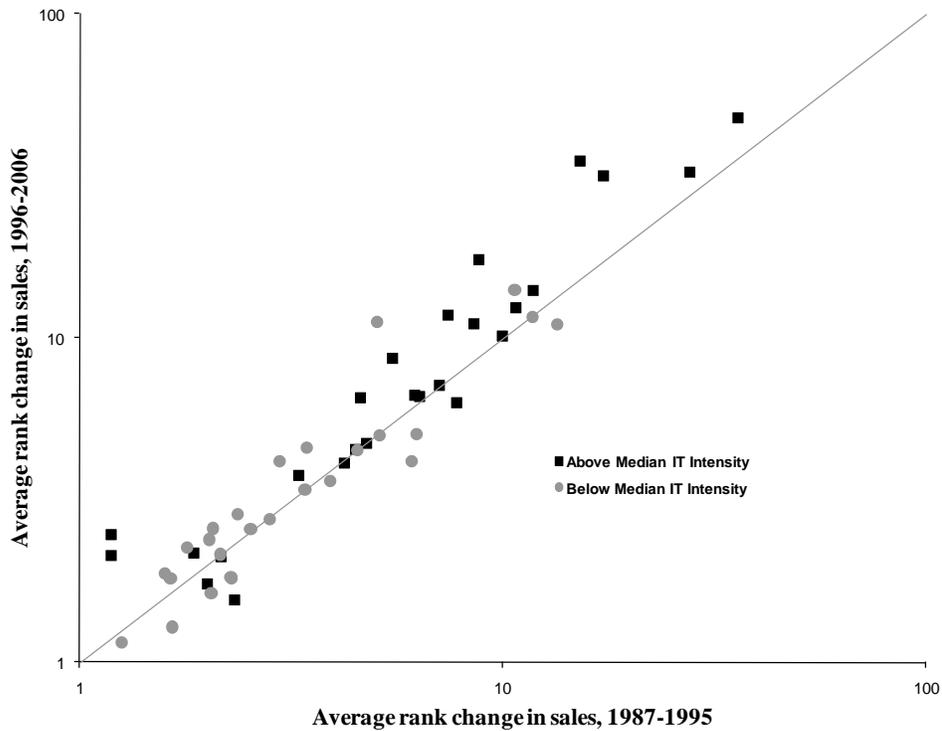


Figure 4a: Scatterplot of average yearly change in sales turbulence, 1987-1995 vs. 1996-2006 (Each data point represents one industry. We use logarithmic scales for the axes to accommodate outliers. Data source: Compustat.)

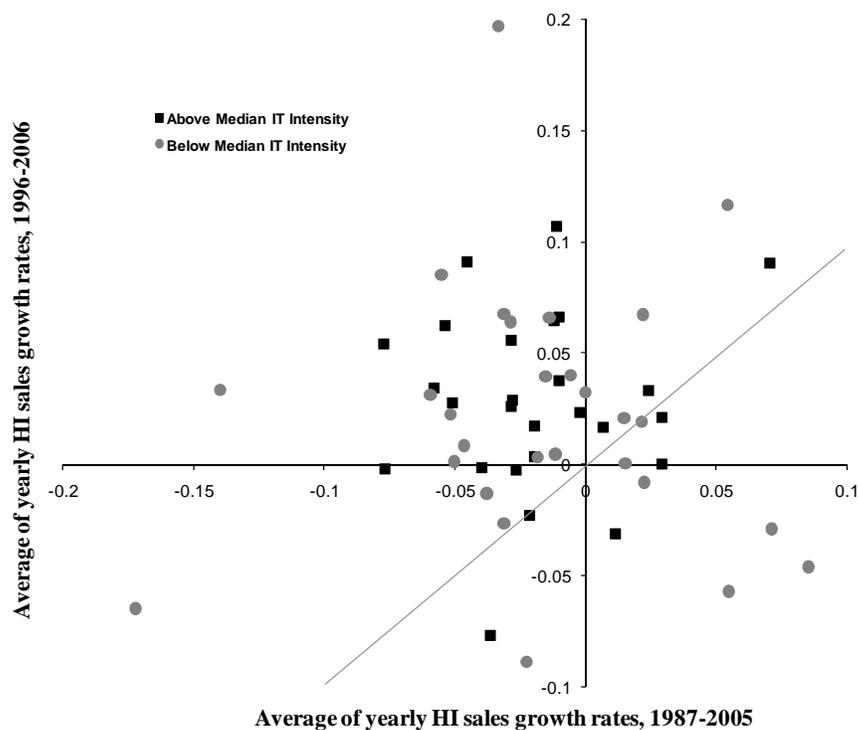


Figure 4b: Scatterplot of average yearly changes in the Herfindahl Index of sales, 1987-1995 vs. 1996-2006 (Each data point represents one industry. Data source: Compustat.)