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INFORMATION TECHNOLOGY, FIRM SIZE, AND INDUSTRIAL CONCENTRATION

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ABSTRACT

Information technologies (IT) have the potential to reshape the organization of firms and the structure of markets. In this paper, we develop a Cournot competition model in which IT enables firms to replicate the routines of their most efficient establishment across locations. This leads to a decline in marginal cost production and the "scale without mass" outcome: because of IT adoption, firms' revenue grows faster than employment. Drawing on US Census microdata covering a panel of about 5000 firms, we confirm that greater investment in IT is associated with increases in sales and market concentration, with smaller and more ambiguous effects on employment. Results from instrumental variables and long-difference models suggest that the association is causal. Because the effect of IT is more pronounced on sales than employment, it compresses the labor share. We also show that IT disproportionately benefits larger firms by enhancing their ability to scale and replicate their operational processes across multiple establishments, markets, and industry segments. By pinpointing how firms operationalize IT gains through replicating high-efficiency routines across establishments, our model and analysis deepen our understanding of the micro-foundation behind recent macro evidence on rising concentration and declining labor share in the digital era.

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1 Introduction

Advances in information technology (IT) have sharply reduced the costs of storing, transferring, and analyzing digital information, reshaping modern economies (Brynjolfsson and McAfee 2014). Because firms and markets are, at their core, information-processing systems (Hayek 1945, Galbraith 1974, Sah and Stiglitz 1986), the broad diffusion of IT is poised to fundamentally transform how economic activities are organized.

This paper examines how IT investment affects firm size, measured by revenue, employment, and market share, and to what extent IT has contributed to the rise of market concentration and the decline in labor share in the United States. We provide novel insights on the micro-foundation behind these phenomena by establishing, both theoretically and empirically, the "scale without mass" trajectory that firms follow as a response to IT adoption. "Scale without mass" refers to firms' ability to expand their output, revenues, and market presence without a proportional increase in labor inputs.

Early theoretical work linked IT with changes in organizational structure and firm boundaries, but offered ambiguous predictions about firm size. One stream of research emphasized automation and labor substitution: by replacing routine tasks, IT and automation could reduce labor demand and shrink firms (e.g., Dewan and Min 1997, Acemoglu et al. 2018). At the same time, other contributions focused on return to scale and market reach, highlighting how IT enables output expansion and customer acquisition, potentially increasing firm size (e.g., Tambe and Hitt 2012, De Ridder 2024, Lashkari et al. 2024). A particular mechanism to achieve that is through coordination and decision rights: by reducing information processing and communication costs, IT can reallocate authority within and across firms, thereby shifting the balance between vertical integration and outsourcing (e.g., Gurbaxani and Whang 1991, Brynjolfsson et al. 1994, Bloom et al. 2014). Taken together, the net effect of IT on firm size is theoretically ambiguous and depends on which mechanisms dominate.

Empirical evidence from earlier studies using data before the 2000s generally found a negative correlation between IT and firm size, consistent with automation and reduced transaction costs channel (e.g., Brynjolfsson et al. 1994, Hitt 1999).

Recent trends, however, point in the opposite direction. By looking into administrative data from the US we observe that average firm size has risen significantly (Figure 1), particularly in finance and real estate, wholesale, retail, and services sectors (Figure 2). These changes disproportionately favor large incumbents, who scale faster and pull further ahead in IT-intensive industries (e.g., Autor et al. 2020, Hsieh and Rossi-Hansberg 2023, Bessen 2020). This in turn has also led to sharp increases in market concentration[1] (Figure 3) for the corresponding sectors. However, the increase in concentration is more pronounced when it is measured by sales than by employment. Such a phenomenon is consistent with the "scale without mass" digitization hypothesis first proposed by Brynjolfsson et al. (2008). This is true for most sectors, including Finance and Real Estate, Wholesale, Services, and even Manufacturing. Importantly, these sectors are also those with the largest surges in IT adoption (Figure 4). This macro-level correlation suggests that IT may play a central role in shaping the observed structural changes and that we should deeper look into firms' growth trajectories as a response to IT adoption.[2]

In fact, a growing literature seeks to explain this shift. Lashkari et al. (2024) proposes a nonhomothetic production function with respect to IT: larger firms adopt IT more intensively and disproportionately benefit from IT cost declines, amplifying returns to scale and fueling aggregate concentration dynamics. Related work similarly links IT diffusion to growing firm size and concentration (Aghion et al. 2023, Hsieh and Rossi-Hansberg 2023, De Ridder 2024). These models generally treat IT as a scale-augmenting input, but typically abstract away from the organizational mechanisms that allow firms to expand.

We address this gap by introducing a model of firm growth through IT-enabled organizational replication. Motivated by the growing prevalence of private equity–backed roll-up strategies in fragmented industries such as healthcare, logistics, and business services (Baik et al. 2024), our

[1]In this paper, we use "industrial concentration" and "market concentration" interchangeably.

[2]In the Appendix, we provide further details on how these stylized facts were derived and relevant figures were produced (A.1).

model highlights how firms use IT to replicate and standardize operations across establishments. These roll-ups rely on IT not only for efficiency and oversight but also for codifying routines and transferring low marginal costs across units, making scalable, multi-unit expansion feasible.[3]

This logic is echoed in high-profile cases. For example, Walmart's pioneering use of IT-enabled supply chain management, which enabled it to quickly duplicate its business operations, is credited with transforming it into a "superstar" firm. Based on a McKinsey Global Institute report, Walmart's growth is responsible for a sixth of retail productivity growth in the late 1990s and early 2000s, growing from 9 percent of the market share in 1987 to 30 percent around 2000 (Basker 2007, Freeman et al. 2011).[4] Similarly, CVS leveraged IT to standardize and scale not only data and software but also business processes, facilitating expansion into thousands of locations while maintaining operational consistency (McAfee and Brynjolfsson 2008).

Our model formalizes this mechanism. We develop a Cournot competition model of firms, each of which relies on labor and IT capital for producing its output. In the model, firms can operate and produce in multiple local markets, with each branch having its own production plan. IT investment allows each firm to transfer knowledge from its most efficient units to others, reducing the marginal cost of production in each branch other than the most efficient one.

We identify three interrelated mechanisms through which IT investment affects firm size: (1) improving average production efficiency (production efficiency effect), (2) expanding output and market share (output expansion effect), and (3) enabling firms to enter more local markets by establishing new business units (local market expansion effect). These effects vary by firm size, market share, and IT intensity. Interestingly, the model leads to different predictions on how IT affects firm sales, employment, and market shares, our main measures of firm size. IT leads to stronger increases in firm sales and market shares for larger multi-unit firms giving rise to industrial concentration. In contrast, IT's effect on employment is ambiguous with firms with a low number

[3] See an example at https://umbrex.com/resources/roll-up-playbook/case-study-successful-roll-up-in-a-fragmented-industry/

[4] https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Americas/US%20productivity%20growth%201995%202000/usprod.pdf. Last access on June 20, 2021.

of employees to be more likely to see their employment to increase as a response to IT adoption. This differential impact of IT on sales and employment suggests that many firms "scale without mass", namely, IT gives firms the ability to achieve significant growth and reach a large customer base without needing to invest heavily in a large workforce.

We test these predictions using restricted micro-level data based on the administrative records from the U.S. Census Bureau on a representative sample of U.S. firms. Our main findings suggest that investment in IT is strongly associated with greater sales and market shares in recent decades, with a one-percent increase in IT intensity raising sales by over one million dollars. These results are robust to various specifications such as long-difference estimations and instrumental variable strategies (Brynjolfsson and Mendelson 1993, Bessen 2020), fixed-effects, sample weights, and alternative IT measures.

In contrast, the employment effects of IT investment are modest and less robust. While both OLS and long-difference estimates yield a positive association, particularly among smaller firms, the effect disappears once we consider long-differences or we instrument for IT, suggesting that after endogeneity is alleviated (Griliches and Hausman 1986), firms can expand sales without a commensurate increase in employment. Even in the specifications where a positive effect is found, its magnitude is, on average, smaller than the magnitude of the IT investment on firm sales. This pattern is emblematic of the “scale without mass" theory of digitization, which is supported not only by our theoretical predictions but also by our main empirical findings. Our estimates also indicate that a one percent increase in IT intensity is associated with roughly a 0.1 percentage-point decline in the labor share.

Additional mechanism tests reveal that the effects of IT on firm sales and market shares are more pronounced for larger firms, potentially through facilitating these firms to operate efficiently with a greater number of units and helping firms enter more local markets and industries. These findings thus help explain the recent rise of industrial concentration and support the hypothesis that IT enables firms to replicate business processes with more production units, reach additional markets and industries. Industry-level analysis shows that a one percent increase in IT intensity is associated with a 0.01 percent increase in the sales share held by the top four firms.

The rest of this paper is organized as follows. Section 2 discusses relevant contributions and walks through some related empirical studies, their main findings and assesses about this paper's contribution with respect to these studies; section 3 develops our theoretical model and the main empirical predictions that motivate our empirical study; section 4 describes the data used for this study; section 5 introduces the empirical methods; section 6 presents the empirical findings; section 7 discusses relevant managerial and practical implications of this study; and section 8 concludes.

2 Literature Review

Our inquiry bridges two complementary research streams. First, classic theories link information costs to firm boundaries, which have evolved towards a growing empirical literature linking the diffusion of information technology to the rise in firm scale and market concentration. Second, a debate asks whether digital technologies displace labor or, by boosting productivity, ultimately expand employment.

2.1 Costs of Information Transfer, Firm Size and Concentration

Hayek (1945) famously points out that information and knowledge are dispersed among participants in economic activities. And, because a firm can be viewed as a nexus of contracts among self-interested individuals, the decision right should be accompanied by information and knowledge to maximize efficiency (Jensen and Meckling 1976). In addition, as ambiguous, incomplete contracts leave residual control with asset owners (Grossman and Hart 1986, Hart and Moore 1988, 1990), whether firms shift information to existing decision-makers (via IT) or reassign decision rights to those who hold the information depends on the relative costs of transmitting and processing knowledge (Brynjolfsson and Mendelson 1993).

These have immediate and significant implications on firm size, as widely dispersed information and knowledge should lead to decentralized decision-making and smaller firms, and vice versa (Garicano 2000). By sharply reducing the cost of collecting, processing, and transmitting information, modern IT upends this calculus on both margins. Low-cost information flows enable headquarters to harvest local knowledge via remote monitoring and to push codified instructions to delegated managers. IT thus improves decision quality and cuts coordination frictions inside the firm and across firm boundaries, but the net implication for firm size remains theoretically ambiguous.

The early wave of empirical work suggested that the market-oriented force dominated. Using data from 1976 to 1989, Brynjolfsson et al. (1994) report that IT investment has been associated with subsequent decreases in the average size of firms. Im et al. (2001, 2013) reach similar conclusions during the 1980s and early 1990s using micro-level data. Analyzing 549 large public firms, Hitt (1999) finds that greater IT use markedly reduces vertical integration and promotes outsourcing. These findings largely align with Malone et al. (1987) and Clemons et al. (1993), who argued that the overall effect of IT in reducing coordination costs should generally shift economic activities towards markets rather than hierarchies.

For the last two decades, the diffusion of information systems such as Enterprise Resource Planning (ERP) suites, integrated accounting and HR management systems, and more recently, advances in cloud computing substantially reduced internal coordination cost. Firm-wide data now flow almost frictionlessly, allowing headquarters and higher managers to monitor distant units and workers and broadcast codified routines back down the hierarchy. When internal coordination costs fall faster than external transaction costs, integration becomes more efficient than outsourcing, nudging firms to centralized ownership. In conjunction with network externalities and economies of scale, IT, therefore, tilts the competitive landscape toward larger firm size, reversing early trends.

The consequences are visible in the growth of "superstar" firms in recent decades, which are well documented by Autor et al. (2020), Covarrubias et al. (2020) and Hsieh and Rossi-Hansberg (2023). Such a phenomenon is particularly evident in the retail sector (Basker et al. 2012, Doms et al. 2004, Foster et al. 2016, Hortaçsu and Syverson 2015). Hsieh and Rossi-Hansberg (2023) formalize this logic and consider a simplified model where a firm pays fixed costs for operating in each industry and each location. While a new technology costs the firm higher fixed costs, it also increases the firm's productivity. They argue that IT, as the general-purpose technology (in the spirit of Rosenberg and Trajtenberg 2004), enables the geographic expansion of firms (particularly in retail, services, and wholesale sectors) by lowering the costs of information transfer, such as monitoring. Consistent with this view, Zolas et al. (2020) find that advanced technology adoption is heavily skewed towards larger and more productive firms.

Recent models capture facets of this shift. Lashkari et al. (2024) model IT demand as nonhomothetic with larger firms adopting IT more intensively, amplifying returns to scale, while Aghion et al. (2023) argue that falling IT costs lower barriers to multi-market entry, raising mark-ups and concentration. Cross-country evidence in De Ridder (2024), Bajgar et al. (2021), and Weiss (2020) and sectoral patterns in Bessen (2020), Kwon et al. (2022) confirm the IT and market concentration link.

Yet, these frameworks leave several organizational questions open: they offer limited guidance on how large firms extend proven processes across space or why revenue growth can outpace gains in headcount.

2.2 Labor Substitution and Productivity Enhancement

In addition to its effect on transaction cost, IT acts directly on the production function, reshaping both output and labor demand. Technology in general, often-cited as a specific type of capital, can substitute labor in the production process (e.g., Arrow et al. 1961), and thus mechanically leads to smaller firm size with respect to firms' employment. If the substitution effect of IT dominates, firms that invest in such type of technology are expected to reduce their labor input. For instance, by evaluating the IT spending of large U.S. firms from 1988 to 1992, Dewan and Min (2008) find evidence that IT substitutes for labor input in production and subsequently leads to restructuring and downsizing. However, firms that adopted advanced technology tend to have higher productivity, and thus increase overall revenue and potentially aggregated employment (e.g., see Brynjolfsson and Mendelson 1993, Berndt and Morrison 1995, Acemoglu and Restrepo 2018 for examples).

Additionally, earlier studies noted a slowing down of productivity growth in the 1970s and 1980s despite the fast adoption of IT - "the IT productivity paradox" (Solow 1987). Subsequent work attributed this paradox to the lag of accumulation of organizational innovation, complementary human capital, business process re-engineering, and other intangible assets that are essential for realizing productivity benefits from IT (Bresnahan et al. 2002, Brynjolfsson and Milgrom 2012). As the investment and accumulation of these intangible assets take time, the productivity-enhancing effect of IT was not able to be captured by earlier empirical studies (Brynjolfsson et al. 2021a). More recent work, however, finds consistent evidence of IT's positive impact on firm productivity (e.g., Brynjolfsson and Hitt 2003, Tambe and Hitt 2012). As intangible capital accumulates, IT-driven productivity gains not only emerge but may become the dominant force over time.

Large firms are particularly well positioned to benefit from this dynamic: they can amortize fixed IT costs and are better equipped with the requisite complementary assets (Brynjolfsson et al. 2021a). Evidence from French manufacturing firms on robotics (Acemoglu et al. 2020) and the propagation of local shocks within corporate networks (Giroud and Mueller 2019, Giroud et al. 2024) shows that multi-unit structures further magnify these gains. As a result, larger firms are increasingly likely to gain competitive advantage and expand their dominance over time.

Taken together, three forces now emerge from the literature. (i) Coordination costs: In the 1980s and 1990s, falling external coordination costs encouraged outsourcing and smaller firms; during the last two decades, steep declines in internal coordination costs—via ERP suites, cloud platforms, and real-time data links—have reverse back toward integration and larger footprints. (ii) Returns to scale: Because IT is largely a fixed-cost, low-marginal-cost input, its diffusion amplifies scale economies; larger firms adopt IT more intensively and reap disproportionate cost declines, reinforcing their advantage. (iii) Complementary assets and productivity: When lower frictions meet better management, richer data, and skilled labor, IT becomes a productivity engine that lets output grow faster than headcount. Large, multi-unit firms sit at the intersection of these forces, spreading fixed IT costs and diffusing best-practice routines throughout their networks.

Yet the precise micro-mechanism that converts an extra dollar of IT into outsized scale remains underexplored.

2.3 Contribution to the Literature

While prior research has established strong links between IT investments and productivity growth, as well as changes in organizational design, much less is known about how IT directly affects firms' ability to scale. This study advances the literature by showing that IT not only enhances efficiency but also enables firms to grow larger without proportionate increases in labor or physical capital—capturing the phenomenon of "scale without mass." By empirically documenting this mechanism, the paper adds a novel dimension to our understanding of how digital technologies are reshaping firm boundaries and competitive dynamics.

To be more specific, our study adds a within-firm replication layer that is missing from the benchmark models in the literature and, in doing so, provides a structural rationale for "scale without mass." Existing models either portray technology as merely reallocating factors across units while leaving marginal costs fixed and non-transferable (Aghion et al. 2023, De Ridder 2024) or treat IT as a symmetric factor-price shock that maintains proportional scaling of inputs and output (Bessen 2020, Lashkari et al. 2024). By contrast, we consider an intra-firm transfer technology that is enabled by IT: a one-time IT outlay lets a firm copy the business processes of its lowest-cost plant and push that efficiency outward to every other branch.

This mechanism generates further predictions that expand prior literature. First, IT-intensive firms optimally expand the number of establishments and locations they serve (the "local market expansion effect"), whereas existing contributions focus on output at a given location.[5] Second, the

[5]Notable exceptions are Aghion et al. (2023) and Hsieh and Rossi-Hansberg (2023). However, their focus differs somewhat. Aghion et al. (2023) is not so much concerned about how firm-level IT investment affects firms' location expansion strategies, as here. Furthermore, Hsieh and Rossi-Hansberg (2023) focus more on service industries while

fall in average marginal cost is convex in market share, so IT disproportionately boosts already-large producers. Together, the replication layer and multi-market choice allow our model to reconcile the very empirical pattern of rising sales, flat (or falling) headcount, declining labor share, and greater concentration in the economy for the last few decades.

Our study also contributes to the debate on the recent slowdown in job reallocation. Prior work shows that employment is moving more slowly from less-productive firms to more-productive ones because firms have become less responsive to idiosyncratic productivity shocks (Foster et al. 2001, 2008, Davis and Haltiwanger 2014, Decker et al. 2020). We find that greater IT investment raises firms' revenue and productivity without a matching increase in employment, offering a mechanism for this weakened responsiveness.

It is also worth noting that this paper builds on and significantly extends the concept of "scale without mass" first articulated by Brynjolfsson et al. (2008), who argued that information technology enables firms to replicate business processes at near-zero marginal cost, leading to greater industry turbulence and concentration. Motivated by their paper that provides macro-level evidence linking IT intensity to structural change across U.S. industries, this paper directly tests micro-level mechanisms underlying those aggregate patterns. Specifically, we i) introduce a formal theoretical framework that models IT adoption, cost reduction, and firm scaling, and we ii) provide firm-level econometric evidence of "scale without mass" hypothesis. In doing so, our study complements and deepens the earlier work by elucidating how IT investment alters firm cost structures and drives scale at the micro level.

The importance of this paper's contribution lies in its implications for theory, empirical evidence, and practice. From a theoretical perspective, the findings help explain the emergence of superstar firms and growing industrial concentration in the digital economy, offering a novel micro-level mechanism that links IT adoption to macro-level outcomes. Empirically, the paper moves the literature forward by measuring and documenting through systematic, firm-level evidence, how IT transforms the scaling properties of firms. It shifts the focus from productivity gains to structural

the "scale without mass" phenomenon (as a response to IT investment) which is central in our analysis is missing.

transformation — showing that IT adoption leads to scalable, intangible-based growth. This new evidence substantiates the idea of “scale without mass,” connecting firm-level IT decisions to economy-wide shifts in firm size distribution, market power, and industrial dynamics. From a managerial and policy perspective, the results illustrate the transformative role of IT as a driver of scalable growth, highlighting both the opportunities it creates for firms to expand and the potential challenges it raises for market competition and labor demand. By connecting IT adoption to the broader phenomenon of scale without mass, the paper provides timely insights into one of the central issues in management science and the digital economy.

3 A Simple Model and Main Theoretical Predictions

We develop a simple theoretical model that connects firm-level IT investment to firm size and industrial concentration, underpinning the mechanism behind the "scale without mass" trajectory for firm growth.

3.1 The Model

Consider an economy with N distinct locations or cities and a population of n firms. A total number of $n_{jt} \geq 2$ firms out of n is present (with a local branch) in city j and in period t, where $j = 1, ..., N$ and $t = 0, 1, ..., \infty$. These firms compete à la Cournot and sell a homogeneous good to consumers.

Each firm i's local branch in city j and in period t simultaneously chooses its individual output level q_{ijt}, where $i = 1, ..., n_{jt}$. Output production requires each firm to incur a production cost that is equal to its marginal cost c_{ijt} multiplied by the output level produced by its local branch. This marginal cost of firm i in city j is drawn independently and identically in each period t from a known continuous distribution, which is characterized by a cumulative density function $F(c_{ijt})$ and a positive probability density function $f(\cdot)$ only within the finite support $c_{ijt} \in [\underline{c}, \overline{c}]$, where

$\overline{c} > \underline{c} \geq 0$.

If firm i has active branches in period t in N_{it} cities, then, it draws N_{it} marginal costs, one for each city it is active. Therefore, $\mathbf{c_{it}} = \{c_{i1t}, c_{i2t}, ..., c_{iN_{it}t}\}$ is the vector of marginal costs firm i incurs in period t in each city it produces output.

Each firm's output is produced by using two inputs: labor and IT capital. Labor is inelastically supplied at a given wage rate w by identical households in each city and time period.[6] IT helps firms to become more efficient in replicating the business processes of their efficient branches with low marginal costs and to transfer this knowledge to branches that are less efficient (Brynjolfsson et al. 2008). In this way, firms can lower the marginal costs of their less efficient branches, achieving a lower average marginal cost across all branches.

Formally, let $c_{it}^{min} = \min\{c_{i1t}, c_{i2t}, ..., c_{iN_{it}t}\}$. Let also $\varphi_{it} \in [0, 1]$ be the ability of firm i in period t to transfer knowledge from its most efficient branch with c_{it}^{min}, say k, to its other branches. For each city $j \neq k$, the marginal cost can be reduced from the initially drawn value c_{ijt} to value $\tilde{c}_{ijt}$, such that: $c_{ijt} - \tilde{c}_{ijt} = \varphi_{it}(c_{ijt} - c_{it}^{min})$. If instead, $j = k$, then, $\tilde{c}_{ikt} = c_{it}^{min}, \forall \varphi_{it} \in [0, 1]$. When $\varphi_{it} = 0$, firm i lacks the ability to replicate the business processes of its most efficient branch, and thus no transfer of knowledge takes place. In such a case, the marginal cost of production equals the one drawn in a given city, c_{ijt}. When $\varphi_{it} = 1$, the firm can fully replicate and transfer the efficiency of its branch k , so that the marginal cost in all cities where it operates becomes c_{it}^{min}.

Variable φ_{it} is strictly increasing in IT investment. Hence, IT helps firm i to become more efficient in its production process as it reduces the marginal cost of production $\tilde{c}_{ijt}$ across its $N_{it} - 1$ least efficient branches.

Firms commit to their spending on IT capital before they observe the marginal costs of competitors and before they set quantities. As a result, IT capital expenditure is considered as a sunk cost when firms make their output decisions (De Ridder 2024).

Let firm i's IT investment fixed cost be denoted by $\Phi_{it}(\varphi_{it}; \xi_{it})$, where ξ_{it} depicts firm i's IT

[6] This is a standard assumption in endogenous growth theory models which produce valid empirical predictions (Aghion and Howitt 1992, Romer 1990).

investment efficiency in period t. Namely, it defines how costly it is for firm i to reduce its marginal cost in each city $j \neq k$ and time t by φ_{it}. Firms differ with respect to their IT investment efficiency. Firms independently and identically draw their ξ_{it} from a known distribution $G(\xi_{it})$ in each period t, with $g(\cdot) > 0$ if and only if $\xi_{it} \in [\underline{\xi}, \overline{\xi}]$, where $\overline{\xi} > \underline{\xi} \geq 0$. The IT investment cost $\Phi_{it}(\varphi_{it}; \xi_{it})$ is strictly increasing and convex on φ_{it}, with $\frac{\partial^2 \Phi_{it}}{\partial \varphi_{it} \partial \xi_{it}} > 0$. A firm i which is IT investment efficient, with low ξ_{it}, has high IT intensity in the sense that it can achieve a given level of IT investment φ_{it} at a lower investment cost $\Phi_{it}(\varphi_{it}; \xi_{it})$. We assume that $\Phi_{it}(\varphi_{it} = 0; \xi_{it}) = 0$, $\forall \xi_{it} \in [\underline{\xi}, \overline{\xi}]$ and that $\Phi_{it}(\varphi_{it} = 1; \xi_{it} = \overline{\xi}) \rightarrow +\infty$.

Note that firms invest in IT in each period t. This is in line with the observed high depreciation rate of IT over time (Li and Hall 2020, Saunders and Brynjolfsson 2016) as well as with the fact that more and more corporations invest in cloud-enabled IT services, where per time period pricing schemes are adopted by cloud computing vendors (Jin and Bai 2022, Jin and McElheran 2024). Firms must therefore continuously invest in order to maintain constant levels of IT.

The production function of firm i in city j and in period t is:

$$q_{ijt} = \frac{w l_{ijt}}{\tilde{c}_{ijt}}, \tag{1}$$

Where l_{ijt} is the firm's production labor. So, a firm with more IT capital produces more output with a given level of labor at wage rate w in all of its branches but the one located in city k.

We assume that firms have to pay a per-period overhead cost, which is a convex function of the number of cities they span (Aghion et al. 2023). Let the overhead cost of firm i being active in $N_{it} > 1$ cities, in period t, be denoted as $\Psi(N_{it}) > 0$, with $\Psi(1) = 0$ and $\Psi(N_{it} = N) \rightarrow +\infty$. Convexity dictates $\Psi(N_{it} + 1) - \Psi(N_{it}) > \Psi(N_{it}) - \Psi(N_{it} - 1)$. This assumption ensures some variation in the number of cities each firm is active in. We can therefore investigate how a firm's IT investment is related to the firm having branches or establishments in more cities or local markets.

The inverse demand function in city j and time period t is $P_{jt}(Q_{jt}) = A_j - b_j Q_{jt}$, where $Q_{jt} = \sum_{i=1}^{n_{jt}} q_{ijt}$ is the total market output and $A_j, b_j > 0$ are city-specific demand parameters.

Hence, the profit function of firm i from city j in time period t is

$$\begin{aligned}\pi_{ijt}(q_{ijt}, c_{ijt}; \varphi_{it}) &= (P(Q_{jt}) - \tilde{c}_{ijt})q_{ijt} \\ &= (A_j - b_j Q_{jt} - \tilde{c}_{ijt})q_{ijt}. \end{aligned} \tag{2}$$

We focus on the interesting case where firm i is active in city j by producing a positive output, $q_{ijt} > 0$ only if it enjoys a strictly positive profit, such that $P(Q_{jt}) > \tilde{c}_{ijt}$.

The profit of firm i from being active in N_{it} cities over period t is given by:

$$\Pi_{it} = \pi_{ikt}(q_{ikt}, c_{it}^{min}) + \sum_{j \neq k} \pi_{ijt}(q_{ijt}, c_{ijt}; \varphi_{it}) - \Phi_{it}(\varphi_{it}; \xi_i) - \Psi(N_{it}). \tag{3}$$

IT investment affects the second and the third term in profit (3). A firm i that invests more on IT sees a larger decline in its marginal cost $\tilde{c}_{ijt}$ in each city $j \neq k$. The respective increase in the IT investment cost $\Phi_{it}(\varphi_{it}; \xi_{it})$ depends on firm's IT investment efficiency ξ_{it}.

The timing of the model in each period t has the following two stages:

1. The IT investment efficiency ξ_{it} is revealed to firm i. Then, each firm i invests $\Phi_{it}(\varphi_{it}, \xi_{it})$ in IT capital.

2. After each firm i observes the marginal costs of its competitors and the realization of its own marginal cost in each city, it chooses (simultaneously with its competitors) its output level per city q_{ijt} and chooses how many cities, N_{it} it will be active.[7] It accordingly hires labor l_{ijt}.

[7]Results remain qualitatively the same if firm i could only observe its own marginal cost in each city j per period t but not the marginal costs of its competitors. In such a case, firm i would consider the expected value of competitors' marginal cost, $E[c]$ when choosing its output production decisions.

3.2 Analysis

We solve this model by backward induction. To understand how IT investment affects output q_{ijt} and profits (2) and (3), we derive the Cournot equilibrium (of the second stage of the model) in Proposition 1.

We assume that $A_j + (n_{jt} - 1)\underline{c} > n_{jt}\overline{c}$ to ensure that the unconstrained Cournot equilibrium is implementable for all realizations of marginal costs and each level of IT investment.

Proposition 1 (Cournot equilibrium output and profit.) *The equilibrium output of firm i in city j in time period t is*

$$q^*_{ijt} = \frac{1}{b_j}\left(\frac{A_j + \sum_{y \neq i} \tilde{c}_{yjt} - n_{jt}\tilde{c}_{ijt}}{n_{jt} + 1}\right). \tag{4}$$

The corresponding profit for firm i in city j in time period t is

$$\pi^*_{ijt} = (A_j - b_j Q^*_{jt} - \tilde{c}_{ijt})q^*_{ijt}, \tag{5}$$

where, $Q^*_{jt} = \sum_{i=1}^{n_{jt}} q^*_{ijt}$.

Proof *All proofs are derived in the appendix.*

Equilibrium output q_{ijt} is strictly increasing in the IT investment of firm i in all cities other than k, since, $\frac{\partial q^*_{ijt}}{\partial \tilde{c}_{ijt}} = -\frac{n_{jt}}{b_j(n_{jt}+1)} < 0$ and given the fact that more IT investment for firm i leads to lower marginal cost, $\tilde{c}_{ijt}$ in these cities.

IT investment by firm i also increases total output produced in city j in period t since $\frac{\partial Q^*_{jt}}{\partial \tilde{c}_{ijt}} = \frac{-1}{b_j(n_{jt}+1)} < 0$. Following equilibrium output (4), firm i's IT investment has two effects on aggregate output produced in city j:

- It reduces output produced by each of its competitors in city j (strategic effect).
- It increases its own output (direct effect).

It is the latter effect that dominates, and therefore total output in city j increases with individual firms' IT investment.

For the equilibrium profit π^*_{ijt}, we have $\frac{\partial \pi^*_{ijt}}{\partial \tilde{c}_{ijt}} = -\frac{n_{jt}}{n_{jt}+1} q^*_{ijt} - \frac{(P(Q^*_{jt}) - \tilde{c}_{ijt}) n_{jt}}{b_j(n_{jt}+1)} < 0$, so, profit π^*_{ijt} is higher in all cities other than k when firm i invests more on IT capital.

A firm i is considered to have a relative IT investment advantage with respect to its competitors in each city j in period t, if the marginal cost of competitors $\frac{\sum_{y \neq i} \tilde{c}_{yjt}}{n_{jt}-1}$ is relatively high with respect to its own marginal cost, $\tilde{c}_{ijt}$. Firm i, therefore, produces more output and realizes higher profit.

Corollary 1 (Firm-level output expansion channel.) *Firm i expands its output production in city $j \neq k$ in period t when it invests more in IT capital. Firm i's IT investment results in less output production by each of its competitors in city j. Hence, the marginal effect of firms i's IT investment is greater on firm i's output than aggregate output in city j. Firm i's output level is, on average, higher if firm i enjoys an IT investment advantage with respect to its competitors in city j.*

The respective equilibrium total profit for firm i from operating branches in N_{it} cities is $\Pi^*_{it}(N_{it})$ which is derived by substituting expression (4) in definition (3). The Cournot equilibrium also defines in how many cities firm i is active in. The following proposition holds:

Proposition 2 (Optimal number of cities.) *The optimal number of cities, N^*_{it}, firm i is active in period t is determined by the following two conditions:*

$$\Pi^*_{it}(N^*_{it} + 1) - \Pi^*_{it}(N^*_{it}) \leq 0,$$
$$\Pi^*_{it}(N^*_{it}) - \Pi^*_{it}(N^*_{it} - 1) > 0.$$

When firm i is active in N_{it} cities, it will only choose to be active in an additional city j if $\pi^*_{ijt} > \Psi(N_{it} + 1) - \Psi(N_{it})$. When firm i achieves a higher level of IT investment, it is more likely that this condition holds for a higher number of cities. So,

Corollary 2 (City expansion channel.) *IT investment helps firms to enter more local markets and have establishments in more distinct locations (cities).*

So, the increase in sales or output as a response to IT investment does not occur only within the cities in which firm i operates. Sales also increase because now firm i is active and produces in more cities and local markets.

The Cournot equilibrium output in each city j has also implications for firm i's employment in each period t. Following (1), firm j employs $l^*_{ijt} = \frac{q^*_{ijt}\tilde{c}_{ijt}}{w}$ workers in city j. IT investment affects equilibrium employment in each city $j \neq k$ through two channels.

- The production efficiency channel: As IT makes production more efficient by reducing marginal cost $\tilde{c}_{ijt}$, the firm needs fewer workers to produce a given level of output. Hence, through this channel labor and IT are substitutes.

- The output expansion channel: As IT increases equilibrium output q^*_{ijt}, firms need to hire more workers in order to meet their increased production goals. Through these channel, labor and IT are complements.

The following lemma applies:

Lemma 1 *The relationship between the number of workers in firm i, in city $j \neq k$ and in period t, l^*_{ijt} and firm i's IT capital depends on whether labor and IT capital are complements or substitutes as following:*

- *Labor and IT capital are complements. l^*_{ijt} is strictly increasing in firm i's IT investment and therefore the output expansion channel dominates when firm i's production efficiency is relatively low with respect to the average production efficiency of its competitors in city j,*

$$A_j + \sum_{y \neq i} \tilde{c}_{yjt} < 2n_{jt}\tilde{c}_{ijt}. \tag{6}$$

- *Labor and IT capital are substitutes. l^*_{ijt} is declining in IT investment if instead, the opposite from (6) holds ($A_j + \sum_{y \neq i} \tilde{c}_{yjt} > 2n_{jt}\tilde{c}_{ijt}$) and firm i's production efficiency is relatively high with respect to the average production efficiency of its competitors in city j.*

Hence, firms with low IT investment competing with firms that have an IT advantage are more likely to see IT and labor as complementary inputs for production. If instead firms have the IT advantage with respect to competitors, they are more likely to see their two inputs as substitutes to each other.

If we look at the employment of firm i in all N^*_{it} cities it has branches, $L_{it} = \sum_{i=1}^{N^*_{it}} l_{ijt}$, then we can identify a third channel through which IT investment affects employment:

- City expansion channel: As IT investment increases, firm i finds more attractive to be active in more cities and employ local workers.

This is a direct effect of Proposition 2. The positive impact of IT investment on the per city profit of firm i, π^*_{ijt} increases the incentives of the firm to be active in more local markets and hire more local workers.

The existence of the production efficiency channel has as a direct implication the decline of the labor share in production. To see this, let $\lambda^*_{ijt} = \frac{l^*_{ijt}}{q^*_{ijt}}$ be the equilibrium labor share in the production of firm i, in city j and in period t. Then,

Corollary 3 *The equilibrium labor share λ^*_{ijt} is strictly declining in firm i's IT investment when $j \neq k$.*

As firms become more efficient by reducing their marginal cost of production, the importance of labor as a production input declines and firms can achieve their output production goals relying less to their workers. This holds even when labor and IT capital are complements. The reason is that the output expansion of IT investment is not fully captured by the respective employment expansion due to the fact that IT investment makes labor more efficient.

To investigate the implications of IT investment on market shares and concentration, let $\alpha^*_{ijt} = \frac{q^*_{ijt}}{Q^*_{jt}}$ be the equilibrium market share of firm i in city j and in period t. Then, $\frac{\partial \alpha^*_{ijt}}{\partial \tilde{c}_{ijt}} = \frac{-n_{jt} Q^*_{jt} + q^*_{ijt}}{b_j (n_{jt}+1)(Q^*_{jt})^2} < 0$ and $\frac{\partial^2 \alpha^*_{ijt}}{\partial (\tilde{c}_{ijt})^2} = 2 \frac{-n_{jt} Q^*_{it} + q^*_{ijt}}{b_j^2 (n_{jt}+1)^2 (Q^*_{jt})^3} < 0$. So, IT investment helps firms to become more efficient, expand their output production schedule and reach a higher market share in each city $j \neq k$. This effect becomes stronger for firms with higher market shares.

These results have implications for market concentration. Let $HHI^*_{jt} = \sum_{i=1}^{n_{jt}} (\alpha^*_{ijt})^2$ be Herfindahl-Hirschman index of market concentration for city j in period t. Firm i's IT investment affects HHI^*_{jt} in two ways:

- It reduces the market share of competitors in each city j and period t (strategic effect). This effect is more pronounced for low market shares of firm i
- It increases its own market share (direct effect). This effect is more pronounced when firm i has higher market share.

In the appendix we show that when firm i has a sufficiently high market share, such that: $\frac{q^*_{ijt}}{Q^*_{jt}} > \frac{2}{n_{jt}+1}$, Firm i's IT investment raises HHI^*_{jt}.

Corollary 4 *Firm i's equilibrium market share α^*_{ijt} is strictly increasing in its own IT investment in city $j \neq k$. This effect is more pronounced when firm i has higher market share. When firm i has a sufficiently high market share in city j, firm i's IT investment leads to a rise in market concentration in that city j.*

In the first stage of each period t, the equilibrium IT investment is derived following expression (3) and Propositions 1 and 2.

Proposition 3 (Equilibrium IT investment.) *The optimal level of IT investment for each firm i in period t is derived by the following first order condition:*

$$\sum_{j \neq k, j=1}^{N^*_{it}-1} \frac{\partial \pi^*_{ijt}}{\partial \varphi_{it}} = \frac{\partial \Phi_{it}(\varphi_{it}; \xi_{it})}{\partial \varphi_{it}}.$$

Firms with higher IT investment efficiency (lower ξ_{it}) reach higher levels of IT investment in equilibrium. Hence, the output expansion channel and the city expansion channel become more important with firm's IT investment efficiency. This implies that firms with high IT investment efficiency are more likely to increase their markups and market shares in a given city $j \neq k$, operate in more cities and to view labor and IT capital as substitutes in their production process. IT investments of these firms are more likely to increase market concentration.

3.3 Empirical Predictions

Our model identifies three channels through which IT investment affects firm size, labor share, and market concentration. Each channel generates empirically testable predictions that guide the analysis in the remainder of the paper.

The effect of IT on sales is governed by the output expansion channel (Corollary 1). In contrast, its effect on employment also involves the production efficiency channel (Lemma 1). While output expansion naturally leads to increases in sales and revenues, its effects on employment are more nuanced as improved labor efficiency due to IT means that fewer workers are needed to achieve the same level of output. IT enables firms to utilize their production network more cost-efficiently and expand into larger markets without a proportional increase in their workforce. In other words, IT leads to "scale without mass."

Empirical Prediction 1 (Sales and Employment) *IT investment allows firms to operate on a greater scale with larger sales. In contrast, the impact of IT investment on firm-level employment is smaller and ambiguous.*

Due to the production efficiency channel, IT also implies a declining labor share (Corollary 3). This is because of the differential impacts of IT on firms' sales versus employment. While IT increases output (Corollary 1), the respective change in employment is more modest or even negative due to the resulted production efficiency (Lemma 1).

Empirical Prediction 2 (Labor share) *IT investment leads to a decline in labor share.*

Another model prediction is that IT makes the replication of business processes much cheaper and allows larger and more productive firms to implement their business model in a large number of markets in a relatively cheaper way. It allows firms to establish more plants and reach more local markets through the city expansion channel (Corollary 2).

Empirical Prediction 3 (Local market expansion) *Firms with higher IT investment establish more locations and enter more local markets.*

Finally, IT contributes to higher market shares, especially among firms that already hold a significant market share. As large firms accumulate a greater level of digital assets and arrive at the technology frontier, their advantage leads them to expand their size to a greater scale. This heterogeneous effect of IT favoring larger firms tends to foster a winner-take-most dynamic, ultimately driving greater market concentration (Corollary 4).

Empirical Prediction 4 (Concentration) *The effect of IT investment on market shares is more pronounced among larger firms than smaller ones and, therefore, IT investment also increases market concentration.*

4 Data and Summary Statistics

Most of the firm-level IT investment data in prior studies about the U.S. economy have limited sample coverage and predate the early 2000s (Tambe and Hitt 2012). In this paper, we examine a detailed firm-level data set from the U.S. Census: the Annual Capital Expenditures Survey (ACES) and its supplement, the Information and Communication Technology Survey (ICTS) from 2004-2013 (excluding 2012 due to the suspension of ICTS).[8] The U.S. Census Bureau collects data on non-capitalized and capitalized business spending for Information and Communication Technology Equipment and Computer Software in the ICTS. It covers all domestic, private, and non-farm businesses, including non-employer businesses. According to the Census website, all

[8]Although the ICTS started in 2003, IT expenditure variables were not recorded during the first year. Thus, we examine these data starting in 2004. Additionally, because of the government shutdown, ICTS was not conducted in 2012.

large firms with at least 500 paid employees are selected from the Business Register (BR) into the sample frame, while smaller companies are stratified by industry and payroll size and selected randomly by strata, resulting in a stratified random sample of roughly 45,000 companies with paid employees, as determined by having nonzero payroll in the previous year.

The key IT-related variables for our study in the ACES and ICTS are IT-related equipment expenditures and capitalized software purchases. In contrast to the external IT data, these databases contain rich and high-quality firm-level IT capital expenditure information for a larger representative sample and can be merged with other surveys conducted under Title 13 (e.g., the LBDRev) to gain access to related firm matrices. One limitation worth noting here, though, is that the ICTS was suspended in 2013 due to reductions in Census Bureau funding levels.[9] Also available in the ACES database is total capital expenditure, which allows us to measure and control in our analysis for non-IT-related capital expenditure.

Complementary to the firm-level IT measures from the ACES and ICTS data, we employ the Revenue-enhanced version LBD (LBDRev) to access restricted information on firm employment, sales, and relevant aspects of firm structures, including the number of establishments, the number of counties in which a particular firm has operations, firm age, and firms' core industry definition. The LBDRev is a product of the U.S. Census's effort of redesigning the earlier longitudinal business database (i.e., LBD) that incorporates information from the Statistics of all private U.S. businesses Chow et al. (2021). It also includes the firm-level employment and revenue information that is documented in the Business Register (Standard Statistical Establishment List Files prior to 2002) data.[10] Given the objective and its prominence, the coverage and quality ensured by the U.S. Census Bureau are hard to match using external resources.

With access to these data, we can report not only the stylized facts above but also build a

[9]Also note that the firm-level data from the ACES and ICTS is the source for the BEA industry-level data of private nonresidential fixed assets, which we use later to explore IT investment trends across major sectors.

[10]For more details of LBD, please see the Census website at: https://www.census.gov/programs-surveys/ces/data/restricted-use-data/longitudinal-business-database.html. For more information on LBDRev, please see Decker et al. (2016). The original version of LBD was initially introduced by Jarmin and Miranda (2002) to create official tabulations to describe the dynamics of the U.S. economy.

large sample of U.S. firms (private and public) with their IT capital expenditures, employment, sales, and other metrics that allow us to further explore the relationship between IT investment and these dynamics. To ensure data quality, and for the purpose of empirical analysis, we drop firms with missing values in IT capital expenditure variables (in the ACES/ICTS) and firms that have zero employees and/or sales (in the LBD and LBDRev). In so doing, we build panel data for about 5000 firms from 2004 to 2013 (excluding 2012, which lacks ICTS survey data).[11]

For this firm-level data, both mean and standard deviation are reported for all key variables in Table 1. On average, firms in our sample generated annual sales exceeding $1 billion and employed more than 3,800 people. The average total annual capital expenditure was slightly over 65 million dollars, about 20% of which was allocated to IT. And on average, firms in our sample spend about six thousand dollars per worker on IT every year. These firms, on average, have about 2.4 and 3.4 percent of the shares in employment and sales, respectively, in their core industry. In addition, these firms on average have 77 establishments, operate in geographic locations with nearly 60 different zip codes, and do business in 4 different six-digit industries. Given these descriptive, it is likely that our sample biases toward larger firms, similar to those in the earlier IT productivity literature (e.g., Tambe and Hitt 2012). However, both ACES and ICTS are purposely designed to capture primarily IT capital investment activity in the U.S. and to be representative, thus relieving concerns about selection bias.[12] Moreover, we conduct additional analysis using weighted regression using the ACES and ICTS sample weights to further test the robustness of our findings against the sample selection issue.

[11]According to the census policy, we round the actual number to the level of thousands.

[12]For more information regarding the sample selection method of the ACES and ICTS, please see the Census websites at: https://www.census.gov/econ/overview/mu2200.html and https://www.census.gov/econ/overview/mu2500.html.

5 Empirical Methods

To test our Empirical Prediction 1, we start by exploring the relationship between firms' investment in IT and their size, measured either by employment or sales. More importantly, we are able to, for the first time, directly measure firms' employment and sales as shares of the total employment and sales of their core industry, and, thereafter, directly link these to industrial concentration because our data covers the universe of U.S. employers in the private sector. In order to tease out the size effect on IT expenditure, we employ IT intensity as our key IT measure by defining it as the IT capital expenditure per worker, following Tambe et al. (2020).[13] The equation can be described as follow:

$$Size_{i,j,t} = \beta_0 + \beta_1 IT_{i,j,t} + \beta_2 nonIT_{i,j,t} + \beta_3 IT_{i,j,t-1} + \beta_4 non_I T_{i,j,t-1} + \beta_X X_{i,j,t} + \varepsilon_{i,j,t} \quad (7)$$

where for each firm i, in the six-digit NAICS industry j, $IT_{i,j,t}$ indicates the measure of IT intensity in year t while $IT_{i,j,t-1}$ indicates the measure of IT intensity in the previous year $t-1$. We also include the measure of non-IT capital expenditure intensity, $nonIT_{i,j,t}$, and its one-year lag, $nonIT_{i,j,t-1}$, to control for the effect of capital expenditure.[14] Here, the main coefficients of interest are β_1, which captures the effect of IT expenditure on firm size for a firm i in industry j in year t. In addition, $X_{i,j,t}$ is a vector of controls that include firm fixed effects, year fixed effects, and industry fixed effects. The firm fixed effects capture time-invariant firm heterogeneity; the year fixed-effects capture the economy-wise homogeneous yearly changes; the industry fixed-effects capture the time-invariant industry-specific unobservables. Both the IT and non-IT measures are in logarithmic forms, as are the size measures. $\varepsilon_{i,j,t}$ is the error term. Standard errors are clustered at the firm level.

Additionally, to test Empirical Prediction 4 and examine whether IT affects the firms with different sizes to a different extent, we explore the heterogeneous effect of IT across firms of

[13]We also use the firm's total IT expenditure level as the regressor for robustness check and report the results in the Appendix.

[14]Similar to the construction of IT intensity variable $IT_{i,j,t}$, we construct the non-IT intensity as the total non-IT expenditure per worker.

different sizes by including the firm size quintiles in the model, as shown below:

$$Size_{i,j,t} = \beta_0 + \beta_1 IT_{i,j,t} + \beta_q Q + \beta_{it,q} IT_{i,j,t} \times Q + \beta_2 nonIT_{i,j,t} + \beta_3 IT_{i,j,t-1} + \beta_4 onoIT_{i,j,t-1} + \beta_X X_{i,j,t} + \varepsilon_{i,j,t} \quad (8)$$

Here, Q is a vector of the indicators for different firm size quintiles. We also include the interaction term of the size quintile indicators and IT investment variable. So the coefficients $\beta_{it,q}$ for each quintile describe the effect difference of IT on that particular size group from the base size group. And the combination of $\beta_{it,q}$ and β_1 together captures the heterogeneous effect of IT across size groups.

5.1 Identification Strategy

Although our fixed effects models control for the firm, industry, and year fixed effects, estimates from earlier specifications might still suffer from the endogeneity issue. For instance, large firms with more resources could be more likely to invest in IT (Dewan et al. 1998) and thus lead to an upward bias on the estimate of IT. Although Tambe and Hitt (2012) find such concerns are less severe in this context, we apply the following strategies to address this potential issue. First, we leverage long-difference models as it is less likely to be subject to biased estimates from measurement error (Greene 1993). This method is adopted in various economic studies in general (e.g., Acemoglu and Restrepo 2018, 2020) and IT productivity research in particular (e.g., Brynjolfsson and Mendelson 1993, Tambe and Hitt 2012).

We further adopt the share of sedentary employees at the industrial level as the instrumental variable (IV) to estimate the effect of IT intensity on a firm's employment and sales, following Bessen (2020). Given that sedentary workers are more likely to work with computers and other IT technologies, firms in industries that have a higher proportion of sedentary workers would, therefore, tend to adopt new IT earlier and more intensively. Building upon the Dictionary of Occupational Titles (DOT) (US Department of Labor 1977), England and Kilbourne (2013) map the sedentariness of nearly 14,000 jobs to census occupation codes.[15] Bessen (2020) calculates the

[15]This data and its description can be accessed via this link: https://www.icpsr.umich.edu/web/ICPSR/

distribution of sedentary occupations for industries using the 2000 census public-use microdata, four years before our data begins. In conjunction with the fact that a firm's sedentary workforce is likely to be influenced by its peers in the same industry, the lagged industrial-level sedentariness is arguably exogenous to a firm's size in the future years. The final data of our IV includes 264 industries that are mostly at four and five-digit NAICS codes. On average, the proportion of sedentary workers is about 43.5%.

6 Results

6.1 IT Intensity and Firm Size

The baseline results following specification (7) are presented in Table 2. Panel A presents the results from the pooled OLS regressions examining the correlation between IT intensity and the sales, as well as the market share of sales. Columns 1 and 2 present the results for sales while columns 3 and 4 present the results for sales share in its core industry. In column 1, the coefficient of $log(ITintensity)$ shows that, controlling for employment, a one percent increase in the firm's IT intensity measure is associated with approximately 0.1 percent increase in sales. In other words, sales increase by over one million dollars. The result is similar when we control for IT and non-IT intensities in the previous year, as presented in column 2. Columns 3 and 4 show the regression results when a firm's sales share is the dependent variable. Similarly, column 3 shows that a one percent increase in IT intensity is associated with a 0.023 percent change in the firm's share of total industrial sales. Controlling for IT and non-IT intensities in the previous year does not change our estimate qualitatively as shown in column 3. All columns in Panel A of Table 2 control for year, industry, and firm fixed effects.

We conduct a similar exercise using employment and market share of employment and present the results in Panel B of Table 2. Given the definition of IT intensity (i.e., using total employment as

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the denominator), it is negatively associated with a firm's employment by construction. Therefore, we use employment and employment share at $t+1$ as our outcome variable. Column 1 shows that a one percent increase in IT intensity is associated with a 0.056 percent increase in firm employment in the following year. And column 2 shows the result is robust when we control for IT and non-IT intensities in the previous year. Columns 3 and 4 show the regression results when a firm's employment share is the dependent variable. They show that higher IT intensity is also associated with large employment shares.

In addition, we perform additional robustness tests. Table 3 presents results from alternative specifications. For each left-hand side variable in Table 2, we include additional variables that control for the number of establishments, the number of zip codes the firm operates in, and the number of industries in Columns 1 and 3 in Panels A and B, respectively. Results are largely similar to those in the corresponding columns in Table 2. Columns 2 and 4 in both panels report results from weighted regressions using the ACES sample weights to address potential selection bias.[16] These results are also consistent with the baseline results in Table 2. We also use IT expenditure as an alternative IT measure and present the results in Table A2. Panel A presents the results for firm sales while Panel B presents the results for firm employment. In both panels, the results are similar to those reported in our baseline models. The coefficients of IT are consistently large, positive, and highly significant, suggesting that higher IT capital investment is positively associated with an increase in firm size with respect to sales, employment, and the corresponding market shares in their core industries.

As evidenced by comparing the coefficients in columns 1 and 2 in Panel A and Panel B across the tables above, the estimated coefficients of IT are generally larger in specifications that use sales as the outcome variable than those that use employment. As both the outcome and explanatory variables are in log terms, this suggests that the elasticity of IT investment on sales

[16]The sample of ACES is selected based on the Business Register (BR). As stated by Census, all companies with at least 500 paid employees are included in the survey; and smaller companies with employees are stratified by industry and payroll size and selected randomly by strata. Companies without employees are selected randomly without regard to industry classification. Please see more details at https://www.census.gov/programs-surveys/aces/about.html.

is more pronounced than its elasticity on employment. This is likely because IT allows firms to improve labor productivity, and thus increase sales without proportionately increasing their labor - a result predicted in Section 3.3. It is also consistent with the findings of Brynjolfsson et al. (2008), Tambe and Hitt (2012), and Acemoglu and Restrepo (2020), and in line with the "scale without mass" theory and the declining trend of labor share, which we predicts in Empirical Prediction 1 above and explore further in the latter sections.[17]

6.2 Identification: Long-Difference Models and Instrumental Variable Estimates

Although Tables 2 and 3 provide suggestive results that an increase in IT intensity is associated with larger firm sizes and higher market shares, these results might still suffer from the potential endogeneity issue. For instance, as noted by Dewan et al. (1998), the scale, scope, and, more importantly, the boundaries of the firm can also affect demand for IT. This implies that the adoption and investment of IT is likely an endogenous choice and thus could cause an upward bias (see Tambe and Hitt 2012 for a detailed discussion). Therefore, we follow prior literature and employ both long-difference and IV approach models in sections 6.2.1 and 6.2.2, respectively.

6.2.1 Long-Difference Models

We first apply long-difference models, which help further tease out measurement errors and strengthen identification (Brynjolfsson and Hitt 2003, Acemoglu and Restrepo 2020). The results are provided in Table 4. Columns 1 to 5 of Panel A present the results for sales from one-year-difference to five-year-difference specifications, respectively.[18] Similar to previous sections, the

[17]One concern is that sales and employment are not measured over the same period, complicating direct comparison. To address this, we report specifications in which both outcomes are measured contemporaneously with the right-hand-side variables and present the results in Table A3. The estimated coefficients for sales are consistently greater than those for employment, further supporting the "scale without mass" hypothesis.

[18]Given the length of our panel data and to ensure we have large enough samples for statistical inference, we report results from difference model up to five-year difference.

left-hand side variable is also the firm's log sales. In all specifications, we control for firm, year, and industry fixed effects. Coefficients from one-year to five-year differences models are all positive and significant at the one percent level, suggesting that an increase in firm IT intensity is associated with larger firm sales. While the magnitude and significance of the coefficients appear to decline slightly in later years, the change in magnitude is not statistically significant and may partly reflect greater noise in sales reporting. The results are largely consistent with our findings above, with respect to sales.

On the other hand, Panel B of Table 4 reports the results of difference models using employment in year $t+1$ as our outcome variable. Although column 1 shows that the change in IT intensity is positively correlated with the change in employment, according to the on-year-difference model, the magnitude of the coefficient is only less than half of the coefficients shown in Table 2 Panel B. And the magnitude of the coefficient for the two-year-difference model is even smaller while it is only statistically significant at the 5 percent level. Furthermore, when it comes to a longer period, the effect of IT intensity on employment is no longer present, as shown in three-year to five-year differences models. These results suggest that the increased IT intensity tends to have a short-term effect on firms' employment size, and to a smaller extent than Table 2 suggests.

These results provide some supporting evidence for the causal relationship between the increasing IT intensity and firm size as measured by sales and employment, consistent with those presented in Tables 2 and 3. However, by comparing the results for sales and employment, the effect on employment seems to be short-lived while the effect on sales seems to be more pronounced and more persistent.

6.2.2 Instrumental Variable Estimates

As noted by Dewan et al. (1998), the scale, scope, and, more importantly, the boundaries of the firm can also affect demand for IT. This indicates that the adoption and investment of IT are likely an endogenous choice and thus could cause an upward bias (see Tambe and Hitt 2012 for a detailed discussion). To further investigate this causal relationship between IT and firm size, we use the share of sedentary workers at the industry level to instrument for IT intensity and present results in Table 5. In all specifications, the first stage shows that our IV is highly correlated with firm IT intensity.

Columns 1 and 2 in Table 5 examine the impact of IT on sales. All specifications control for the firm's non-IT intensity, current year employment size, and year fixed effect, and the coefficient of interest is the IT intensity. Column 2 controls for additional industry fixed-effects at three-digit level of NAICS, which is the best we can do as our instrumental variable is largely at four-digit level. Both columns 1 and 2 show that a higher IT intensity leads to a larger firm size in sales, largely consistent with the findings in earlier models. A one percentage increase in IT intensity is associated with about a 0.65 percent increase in firms' sales.

Columns 3 and 4 in Table 5 present the results for employment in year $t + 1$ following the same IV strategy. Unlike the sales specifications, columns 3 and 4 yield IT-intensity coefficients that are not statistically significant, contradicting the significant estimates reported earlier in Tables 2, 3, and 4. The IV estimates reveal a non-effect of IT intensity on firm size with respect to employment, reinforcing the ambiguous relationship posited in Empirical Prediction 1.

The comparison between the results for employment and the ones for sales (columns 1 and 2) suggests that investment in IT likely enhances a firm's sales performance without expanding its employment, consistent with the phenomenon of "scale without mass" (Brynjolfsson et al. 2008).

6.3 IT intensity and Labor Share

Previous sections provide evidence that IT intensity could lead to faster growth in firms' sales but without expanding their employment to a similar scale, suggesting a declining labor share of firms' output as described in the Empirical Prediction 2 in Section 3.3. In this section, we take a further step and analyze the relationship between the investment in IT and the firm's labor share. Similar to the previous sections, we study such correlation by estimating Equation 7 with firm-level labor share as the outcome variable of interest. We follow Autor et al. (2020) and define labor share as the ratio of payroll to sales. Table 6 presents the results. The baseline result in Panel A column 1 shows that a one percent increase in IT intensity is associated with a 0.1 percent decline in labor share. And the results are robust across specifications with lagged independent variables (column 2), with additional controls for the number of establishments, zip codes, and industry (column 3), and weighted regression (column 4). In addition, following Sections 6.2.1 and 6.2.2 to address the potential endogeneity issue, we also present results from long-difference models (Panel B) and IV strategy (Panel A, columns 5-6) in Table 6. Although the IV estimate with industry fixed effects (Panel A, column 6) is less precise, results are largely consistent with the baseline, supporting a causal interpretation of the negative relationship between IT intensity and firms' labor share.

6.4 Mechanism Tests

As predicted by our model described in Section 3, IT allows firms to codify their operation, facilitate duplication of their business process in more production units and markets, and thus lead to larger firm size. We further investigate this mechanism and test whether IT is associated with additional outcome variables of interest, including the total number of establishments, number of zip codes, and industries that firms operate in, and present the results in Table 7.

Panel A presents the correlation between IT and the number of establishments and shows that a one percent increase in IT intensity is associated with a 0.03 percent increase in the number of establishments. Similarly, Panel B and Panel C show that IT is also associated with the increase in the number of zip codes and the number of industries, respectively. The coefficients for IT within IV strategies using the sedentariness of employees are also positive and statistically significant, as presented in Columns 3 and 4 of each panel. These results suggest that investment in IT is likely to increase the firm size through its capability of lowering internal coordination and business process duplication costs, allowing firms to expand with more establishments, and enter additional physical and product markets.

6.5 Effect Heterogeneity and Implication in Industrial Concentration

Given that the benefits of economies of scale and the accumulation of tangible and intangible complements benefit larger firms (e.g., Acemoglu and Restrepo 2018, Feigenbaum and Gross 2021, Tambe and Hitt 2012, Bresnahan et al. 2002, Brynjolfsson and Milgrom 2012, Brynjolfsson et al. 2021b, the contribution of IT to firm growth is likely to vary across firm size groups as they are more likely to grow through the aforementioned enabling effects of IT. Section 3 illustrates the heterogeneous effect of IT and states how market concentration arises while larger firms benefit more from IT in our Empirical Prediction 4.

Following equation 8, we thus estimate the marginal effect of IT intensity on firm size across firms of different sizes and plot the regression coefficients for sales, employment, and labor share in Figure 5. Here, we split firms into quintiles according to their position in the distribution of sales within their primary industry.[19] The result in Panel (a) shows that a higher IT intensity is associated with greater sales, but this effect increases monotonically with firm sizes and is only significantly different from zero for larger firms. This suggests that although the average effect of IT on firms' sales might be positive, the disproportional larger gain for larger firms suggests an increasing return to scale of IT investment. Given the extensive business adoption of IT across a wide range of industries, our results here provide supporting evidence that IT is one of the driving forces for increasing concentration over time, which we explore further using industry-level analysis in Section 6.6. In addition, the larger effects of IT on sales (compared to employment) are more pronounced among the firms in larger size quintiles.

Result in Panel (b) also indicates that a higher IT intensity is associated with greater employment for all size quintiles although the effect of IT seems to have a greater effect on small firms while larger firms are affected to a smaller extent in terms of the percentage change. However, because the average firm size increases rapidly from the first to the fifty quintiles, the effect magnitude in terms of level actually increases monotonically.

[19]This is also to ensure that we comply with the US Census disclosure avoidance rules.

Results in earlier sections show that the estimated effect of IT on sales is much larger than its effect on employment, especially in the IV estimation (see Table 5) and thus would on average lead to a decline in labor share (i.e., Table 6). In panel (c) of Figure 5, we further reveal that this effect is much more pronounced in larger firms. In fact, the effect of IT on labor share is positive (though noisy) for firms in the bottom size quintile but declines across the size categories, and becomes more negative and highly significant for firms in the top three size quintiles. This is consistent with the results presented in Panels (a) and (b).

6.6 A Revisit - IT Expenditure and Industrial Concentration

In the above section, we demonstrate that IT provides disproportional benefits to larger firms, implying that the adoption of IT is one of the factors of the increasing industry concentration. Therefore, following Bessen (2020) we aggregate our data and conduct an industry-level analysis using the long-difference model (Brynjolfsson and Hitt 2003, Bessen 2020).[20] The basic equation can be described as equation 9, as shown below:

$$\Delta Concentration_j = \beta_0 + \beta_{IT} \Delta IT_j + \varepsilon_{j,t} \tag{9}$$

Where for each industry j (at the six-digit NAICS level) in year t, $\Delta Concentration_j$ indicates the difference in the industry concentration (e.g., HHI, CR4, and Top 10% for both employment and sales) between 2004 and 2013. ΔIT_j indicates the differences in average IT hardware and software capital expenditure between 2004 and 2013 in a given industry. The coefficient of interest in equation 9 is β_{IT}, which indicates how a change in IT expenditure contributes to a change in industry concentration.

The corresponding results from the regression above are presented in Table 8. Columns 1 to 3 present results of three widely used industrial concentration measures–HHI, CR4, and the share of sales in the top 10% firms–while columns 4 to 6 present results from similar models for employment. The left-hand side variables are the change in log industrial concentration measures

[20] We employ the longitudinally consistent 6-digit FK NAICS codes.

between 2004 and 2013. The right-hand side variable in all specifications is the difference in log IT expenditure between 2004 and 2013. The regression samples consist of 815 six-digit NAICS industries.

As indicated in columns 1 to 3 in Table 8, the change in IT capital expenditure is positively and significantly associated with changes in sales concentration as measured in all three different metrics. This indicates that industries with a larger IT expenditure growth during the period of 2004 to 2013 also experienced a faster increase in industrial concentration. In column 1, for example, an one percent increase in the industry average IT expenditure was associated with about a 0.08 percent increase in the sales HHI index. Columns 2 and 3 show similar relationships for different measures. Likewise, columns 4 to 6 in Table 8 indicate that the change in IT capital expenditure is positively correlated with the employment concentration measures. The coefficient of $\delta log(IT)$ presented in column 4 is 0.08, a magnitude similar to the coefficient in column 1. All results are statistically significant at the one percent level. Our findings are largely consistent with those in the prior study (Bessen 2020).

Combining these findings with earlier results in Figure 5, we document an effect of IT that leads to increased market concentration with the rise of superstar firms in the last decade. It further indicates a troubling trend where a significant amount of the workforce will be substituted by IT as firms become more digitized, with larger and more productive firms dominating our economy.

7 Managerial and policy Implications

The findings of this study have far-reaching implications for how managers and policymakers understand growth, strategy, and competition in the digital economy. By demonstrating that IT enables firms to expand in scale without proportionate increases in tangible assets or labor, the study emphasizes IT as a central strategic driver of organizational growth. This "scale without mass" dynamic is transforming how firms compete, how industries consolidate, and how value is created and captured.

IT investments fundamentally alter the economics of scaling. In traditional growth models, expansion required accumulating “mass” — factories, stores, employees. By contrast, IT enables firms to expand output, sales, or market presence without proportional growth in physical or human inputs. The high-fixed-cost and low-marginal-cost nature of IT shifts the economy toward an intangible-based, digitally scalable growth model. Rather than asking "How much can we save?", managers nowadays should ask "How much can we scale?" Firms that deploy IT more effectively gain lasting competitive advantages because digital scalability fosters winner-take-most dynamics. IT investment should be evaluated as capacity-building for nonlinear growth, not merely operational efficiency.

These dynamics directly explain the proliferation of private equity roll-ups in fragmented industries such as healthcare, logistics, and business services. These sectors are traditionally composed of numerous small, localized firms that have limited economies of scale. IT creates precisely the technological infrastructure that makes roll-ups economically attractive. For private equity and corporate acquirers, this implies two priorities. First, target selection should assess digital readiness alongside traditional metrics. Second, post-merger value creation increasingly depends on technological integration. The ability to integrate acquisitions onto common platforms determines whether portfolios achieve true scale economies or remain collections of independent operations.

For policymakers, these findings raise important considerations for competition policy and economic development. The scale-without-mass dynamic accelerates market concentration, as firms with superior IT capabilities can expand rapidly across geographic and product markets. Traditional antitrust metrics focused on physical assets or employment may understate actual market power when firms achieve dominance through digital infrastructure rather than tangible assets.

Overall, the findings of this paper offers significant managerial and policy implications. IT adoption has evolved from an operational choice into a strategic imperative that shapes not only how firms grow, but also how rapidly they can scale. The ability to achieve scale without mass underpins many of the defining features of the modern economy: the dominance of digital platforms, the rise of PE-backed roll-ups, and the transformation of traditional incumbents like Walmart into technology-powered enterprises.

8 Summary and Conclusion

Economic activities, either within firms or in markets, entails information processing. As digital technology has advanced over the past decades, the steep decline in the cost of processing information has, therefore, inevitably altered how the boundaries between firms and markets are drawn.

Recent evidence shows that the average firm size and industrial concentration in the U.S. have increased, particularly in those sectors with the sharpest increases in the adoption of IT, such as wholesale, retail, finance, and real estate, and services sectors. This suggests that lowering internal coordinating costs and/or enhancing productivity with market expansion have been the dominant effects of IT in recent years.

This paper set out to examine the relationship between information IT adoption and firm size. Building on prior work that has documented the productivity effects of IT, we study whether digital technologies also shape the scale of firms, and if so, in what direction. Using a large firm-level dataset, we find consistent evidence that IT investment is positively associated with firm size, with effects that are stronger in services and knowledge-intensive industries.

Firms that adopt IT are able to expand their revenues and outputs more rapidly than their employment or tangible capital bases. In other words, IT enables firms to grow larger without proportionally adding more workers or physical assets. This finding adds a new dimension to the IT–firm literature: rather than focusing solely on efficiency gains, our evidence demonstrates that IT alters the very nature of firm growth.

Our study provides one of the first large-scale evidence of how IT adoption reshapes the scaling logic of firms. This advances our theoretical understanding of the role of digital technologies in shaping firm boundaries and contributes to the broader literature on organizational economics, firm dynamics, and industrial organization.

The implications of these findings extend to market structure and competition. If IT systematically enables firms to scale without mass, then digitally intensive firms will tend to capture increasing market shares while relying less heavily on traditional inputs such as labor. This dynamic helps explain the rise of superstar firms, the widening dispersion in firm performance, and the growing concentration observed in many industries. Our results thus link firm-level IT choices to macro-level trends in concentration and inequality.

In conclusion, we find that IT adoption does more than boost productivity: it fundamentally reshapes the scale and structure of firms. We highlight a mechanism that helps explain the rise of superstar firms and growing concentration.

Recent advances in artificial intelligence (AI) promise similarly far-reaching consequences. Like earlier waves of IT, AI functions as a general-purpose technology (Eloundou et al. 2024). By raising labor productivity, AI lets firms expand revenue without enlarging their workforces proportionally. Large incumbents are particularly well positioned to benefit disproportionately: their vast proprietary data, greater capacity to finance capital-intensive compute infrastructure, and deeper pools of specialized talent create powerful complementarities with AI. Consequently, the diffusion of AI is likely to reinforce—and perhaps accelerate—the ongoing rise in market concentration, in the long-run, allowing firms to achieve unprecedented "scale without mass".

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Figures and Tables

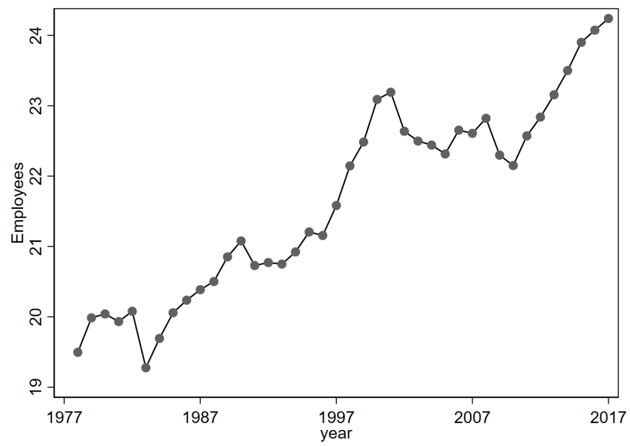
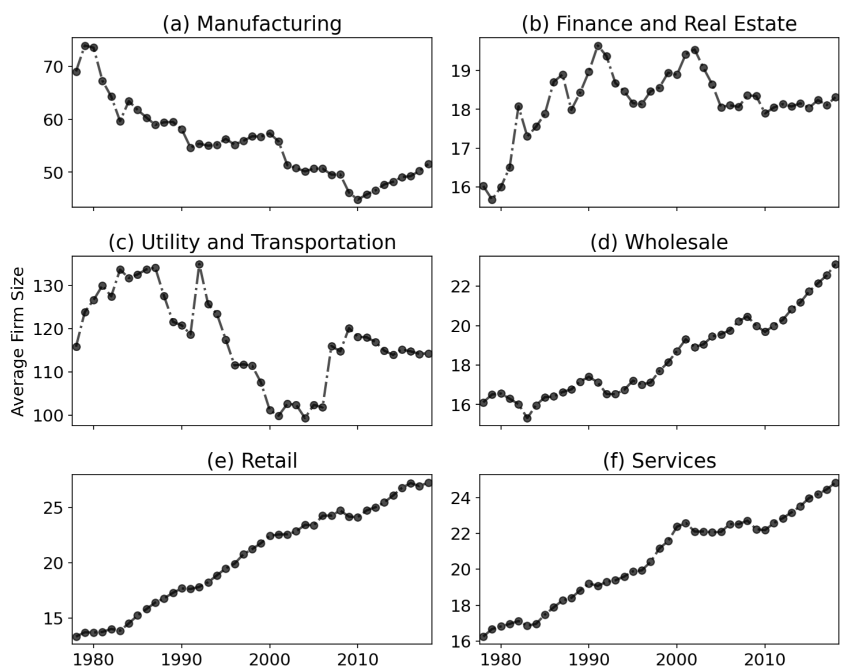


Figure 1: Average Firm Employment Size in the US (1978-2017)

Note: This figure presents the evolution of average employment of U.S. firms from 1978 to 2017. The reported statistics are based on the authors' calculations using the publicly available Business Dynamics Statistics (BDS) data from the U.S. Census Bureau.



Average Firm Size Across Major Sectors

Figure 2: Average Firm Employment Size in the US (1978-2017)

Note: This figure presents the evolution of average firm employment in six major sectors. The reported statistics are based on the authors' calculations using the publicly available Business Dynamics Statistics (BDS) data.

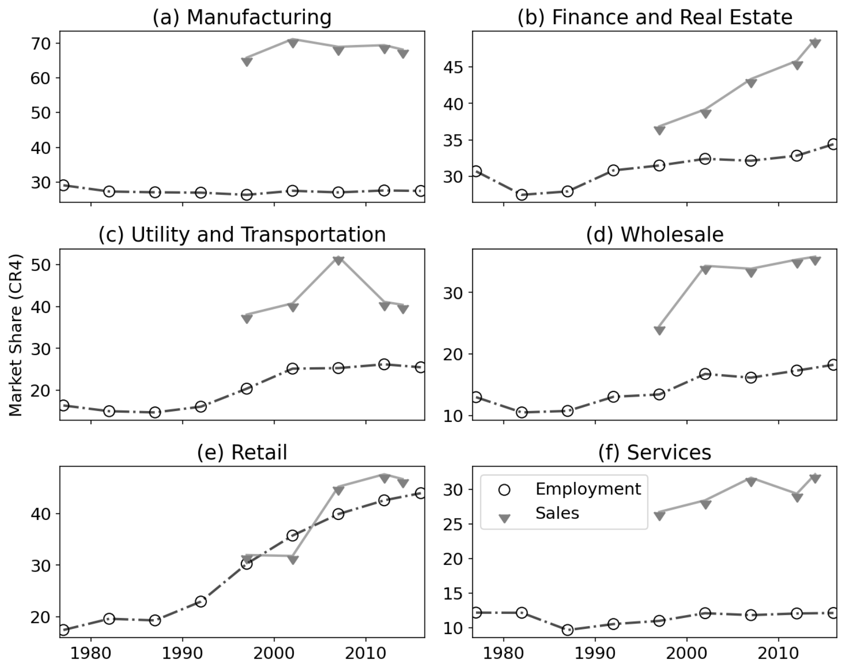


Figure 3: Sales and Employment Concentration Rates for Top 4 Firms

Note: Concentration Rate 4 (CR4) at six major sectors from the weighted average of CR4 at 6-digit NAICS. Authors' calculations using the Revenue-enhanced version Longitudinal Business Database (LBDRev). CR4 is calculated by taking the shares of the four largest firms in the industry. The definition of sectors is largely derived from Autor et al. (2020). However, their paper uses time-consistent four-digit SIC codes while ours uses time-consistent six-digit NAICS codes.

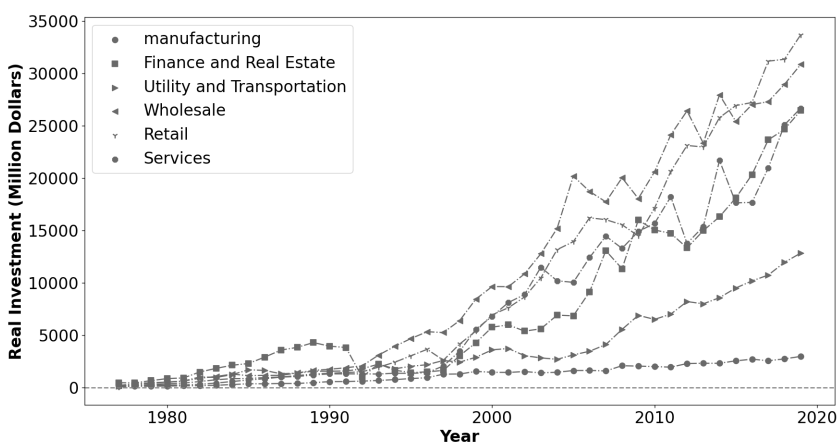
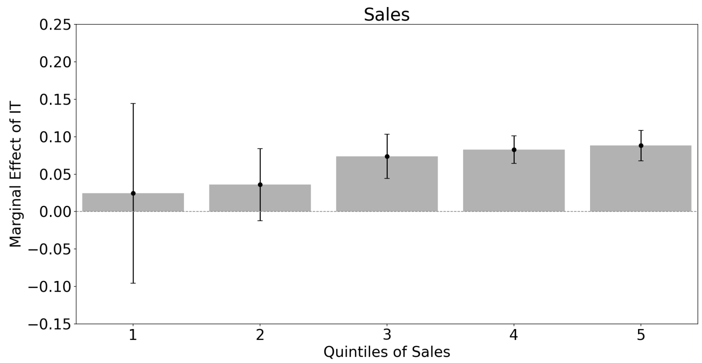
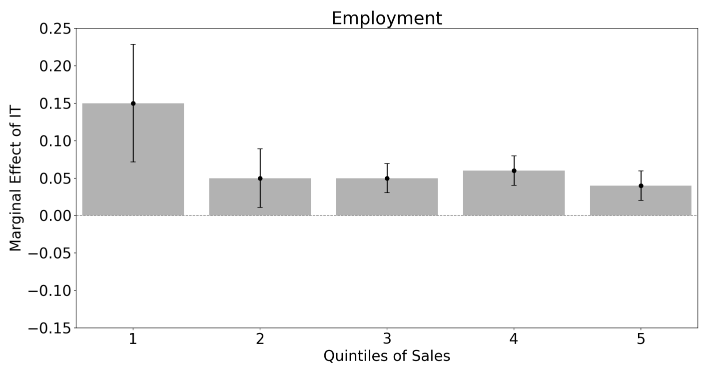


Figure 4: Real IT Capital Investment by Sectors

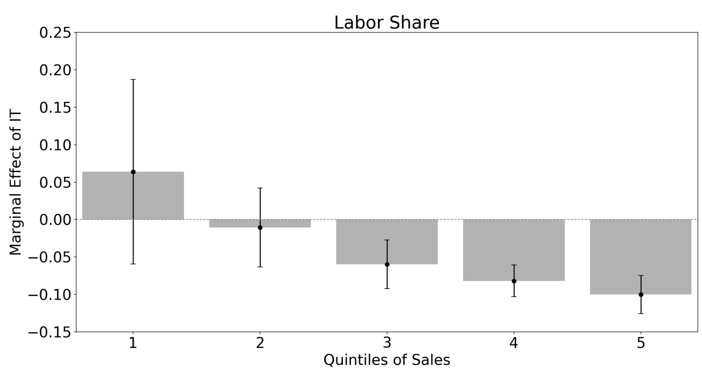
Note: The reported statistics are based on the authors' calculation using investment series for private nonresidential fixed assets on all IT-related categories from the Bureau of Economic Analysis (BEA), including mainframes, PCs, DASDs, printers, terminals, tape drives, storage devices, system integrators, prepackaged software, custom software, and own-account software.



(a)



(b)



(c)

Figure 5: Heterogeneous Returns of IT Intensity on Firm Size by Size Category

Note: These figures present the estimated marginal effects of IT intensity on firm sales (Panel a), employment (Panel b), and labor share (Panel c). Quintiles are based on sales distribution. Vertical lines represent the 95% confidence intervals.

Table 1: Summary Statistics for Key Firm-level Variables

Variables	Mean	Standard Deviation	Observations
Sales (M)	1,121	6,260	~50,000
Employment	3,850	20,890	~50,000
IT Capital Expenditure (K)	12,680	185,600	~50,000
Total Capital Expenditure (K)	65,210	502,900	~50,000
IT Expenditure per worker (K)	6.02	201.8	~50,000
Share of Employment (%)	2.35	6.70	~50,000
Share of Sales (%)	3.43	9.84	~50,000
Labor Share (%)	0.697	6.208	~50,000
Number of establishments	77.42	404.2	~50,000
Number of zip codes	58.39	274.6	~50,000
Number of industries	4.327	5.303	~50,000

Note: Sales are in millions of dollars. Capital expenditures are in thousands of dollars. Firm's sales share is calculated as the share of firm's sales in the total sales of the six-digit NAICS industry. Firm's employment share is calculated as the share of the firm's employment in the total employment of the six-digit NAICS industry. Labor share is calculated as the ratio of payroll to sales of the firm. The number of observations is rounded to the nearest thousand, in accordance with Census Bureau disclosure rules.

Table 2: IT Intensity, Firm Size, and Market Share
Baseline Results

Panel A: Sales and Sales Share

Dep.Var.	Sales		Sales Share	
	1	2	3	4
log(IT Intensity)	0.101***	0.098***	0.023***	0.022***
	(0.008)	(0.008)	(0.004)	(0.004)
log(Non-IT Intensity)	0.043***	0.042***	0.010***	0.009***
	(0.004)	(0.003)	(0.002)	(0.002)
log(IT Intensity)(t-1)		0.010		-0.000
		(0.007)		(0.004)
log(Non-IT Intensity)(t-1)		0.010***		0.004***
		(0.003)		(0.002)
Log(Emp)	0.382***	0.381***	0.091***	0.090***
	(0.020)	(0.020)	(0.006)	(0.006)
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y
R-squared	0.965	0.965	0.972	0.972
Observations	~50,000	~50,000	~50,000	~50,000

Panel B: Employment and Employment Share

Dep.Var.	Employment (t+1)		Employment Share (t+1)	
	1	2	3	4
log(IT Intensity)	0.056***	0.050***	0.015***	0.011*
	(0.007)	(0.008)	(0.005)	(0.006)
log(Non-IT Intensity)	0.023***	0.023***	0.006**	0.002
	(0.003)	(0.003)	(0.002)	(0.003)
log(IT Intensity)(t-1)		0.025***		0.012*
		(0.008)		(0.006)
log(Non-IT Intensity)(t-1)		0.011***		0.003
		(0.003)		(0.002)
Log(Emp)	0.423***	0.368***	0.118***	0.097***
	(0.018)	(0.023)	(0.011)	(0.014)
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y
R-squared	0.966	0.969	0.940	0.945
Observations	~50,000	~35,000	~50,000	~35,000

Note: Firm's sales share is calculated as the share of firm's sales in the total sales of the six-digit NAICS industry. Firm's employment share is calculated as the share of the firm's employment in the total employment of the six-digit NAICS industry. For employment and employment share, we use the values at $t + 1$ as our outcome variable because IT intensity is negatively associated with a firm's concurrent employment by construction. The number of observations is rounded to the nearest thousand, in accordance with Census Bureau disclosure rules. Robust standard errors are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table 3: IT Intensity, Firm Size, and Market Share
Robustness Checks

Panel A: Sales and Sales Share

Dep.Var.	Sales		Sales Share	
	1	2	3	4
log(IT Intensity)	0.098***	0.098***	0.021***	0.022***
	(0.008)	(0.013)	(0.004)	(0.004)
log(Non-IT Intensity)	0.043***	0.045***	0.009***	0.009***
	(0.003)	(0.004)	(0.002)	(0.002)
Log(Emp)	0.349***	0.379***	0.071***	0.085***
	(0.022)	(0.021)	(0.006)	(0.006)
Additional Controls	Y		Y	
Weighted		Y		Y
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y
R-squared	0.965	0.969	0.972	0.975
Observations	~50,000	~50,000	~50,000	~50,000

Panel B: Employment and Employment Share

Dep.Var.	Employment (t+1)		Employment Share (t+1)	
	1	2	3	4
log(IT Intensity)	0.053***	0.051***	0.014***	0.013**
	(0.006)	(0.007)	(0.005)	(0.005)
log(Non-IT Intensity)	0.023***	0.020***	0.006**	0.004**
	(0.003)	(0.003)	(0.002)	(0.002)
Log(Emp)	0.391***	0.402***	0.096***	0.111***
	(0.020)	(0.023)	(0.011)	(0.010)
Additional Controls	Y		Y	
Weighted		Y		Y
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y
R-squared	0.967	0.974	0.940	0.941
Observations	~50,000	~50,000	~50,000	~50,000

Note: Firm's sales share is calculated as the share of firm's sales in the total sales of the six-digit NAICS industry. Firm's employment share is calculated as the share of the firm's employment in the total employment of the six-digit NAICS industry. For employment and employment share, we use the values at $t + 1$ as our outcome variable because IT intensity is negatively associated with a firm's concurrent employment by construction. Columns 1 and 3 add additional controls including the number of zip codes, number of establishments, and number of industries while columns 2 and 4 are weighted regressions using ACES sample weights. The number of observations is rounded to the nearest thousand, in accordance with Census Bureau disclosure rules. Robust standard errors are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Long-Difference Models for IT Intensity and Firm Size

Panel A: Sales

Difference Length	1 year	2 years	3 years	4 years	5 years
log(IT Intensity)	0.043***	0.034***	0.031***	0.025**	0.024**
	(0.006)	(0.009)	(0.010)	(0.010)	(0.011)
Observations	~30000	~24000	~19000	~14000	~10000

Panel B: Employment (t+1)

Difference Length	1 year	2 years	3 years	4 years	5 years
log(IT Intensity)	0.0232***	0.0152**	0.0093	0.004	-0.0024
	(0.0063)	(0.0068)	(0.0075)	(0.0081)	(0.0080)
Observations	~26000	~20000	~15000	~11000	~7000

Note: The dependent variables are one-year to five-year differences of the logarithm of the size variables, respectively. We use employment at $t+1$ as our outcome variable because IT intensity is negatively associated with a firm's concurrent employment by construction. The independent variables are one-year to five-year differences in the logarithm of current-year IT intensity, respectively. Robust standard errors are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table 5: Instrumental Variable Models
Sedentariness

Dep.Var.	Sales		Employment (t+1)	
	1	2	3	4
log(IT Intensity)	0.645***	0.660***	0.002	0.007
	(0.043)	(0.135)	(0.006)	(0.027)
log(Non-IT Intensity)	0.325***	0.168***	0.017***	0.028***
	(0.016)	(0.037)	(0.002)	(0.007)
Log(Emp)	0.938***	0.927***	0.984***	0.978***
	(0.008)	(0.009)	(0.001)	(0.002)
1st Stage coefficient	0.935***	0.593***	0.928***	0.606***
	(0.025)	(0.051)	(0.025)	(0.051)
KP Chi-sq	966.6	132	968.1	140.9
CD Wald F	5690	355.7	5800	384.3
KP Wald F	1408	133.2	1409	142.6
Year FE	Y	Y	Y	Y
Industry FE		Y		Y
R-squared	0.674	0.692	0.954	0.945
Observations	~50,000	~50,000	~50,000	~50,000

Note: The dependent variables are identical to columns 1 and 2 of Panels A and B in Table 2. We use the share of sedentary workers at the industry level from 2000 to instrument for IT intensity. The number of observations is rounded to the nearest thousand, in accordance with Census Bureau disclosure rules. Robust standard errors are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table 6: IT Intensity and Labor Share

Panel A: OLS and IV

Dep.Var.	Labor Share					
	1	2	3	4	5	6
Model	Baseline	w/ Lag	Robust	Weighted	IV (Sedentariness)	
Log(IT Intensity)	-0.095***	-0.094***	-0.094***	-0.091***	-0.100**	0.061
	(0.009)	(0.009)	(0.009)	(0.012)	(0.039)	(0.121)
Log(Non-IT Int.)	-0.031***	-0.030***	-0.031***	-0.032***	-0.282***	-0.240***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.015)	(0.034)
Log(Emp)	0.418***	0.419***	0.427***	0.420***	0.023***	0.038***
	(0.020)	(0.020)	(0.022)	(0.023)	(0.008)	(0.009)
Firm FE	Y	Y	Y	Y		
Year FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y		Y
R-squared	0.882	0.882	0.882	0.883	0.178	0.063
Observations	~50,000	~50,000	~50,000	~50,000	~50,000	~50,000

Panel B: Long Difference Models

Difference Length	1 year	2 years	3 years	4 years	5 years
log(IT Intensity)	-0.057***	-0.051***	-0.051***	-0.047***	-0.049***
	(0.008)	(0.011)	(0.013)	(0.014)	(0.016)
Observations	~30000	~24000	~19000	~14000	~10000

Note: Labor share is calculated as the ratio of payroll to sales of the firm. Column 2 in Panel A includes IT intensity and non-IT intensity from the previous year. The dependent variables in Panel B are one-year to five-year differences in the logarithm of labor share, respectively. The independent variables are one-year to five-year differences in the logarithm of current-year IT intensity, respectively. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Establishments, Zip Codes, and Industries

Panel A: Number of Establishments

	1	2	3	4
Model	Baseline	w/ Lag	IV (Sedentariness)	
log(IT Intensity)	0.0321***	0.0327***	0.1908***	0.9641***
	(0.0064)	(0.0062)	(0.0708)	(0.2800)
Log(Non-IT Int.)	0.0015	0.0019	-0.0305	-0.1922**
	(0.0021)	(0.0021)	(0.0252)	(0.0762)
Log(Emp)	0.3515***	0.3521***	0.8254***	0.8097***
	(0.0155)	(0.0156)	(0.0109)	(0.0144)
Firm FE	Y	Y		
Year FE	Y	Y	Y	Y
Industry FE	Y	Y		Y
R-squared	0.9876	0.9876	0.3514	0.3604
Observations	~50,000	~50,000	~50,000	~50,000

Panel B: Number of Zip Codes

	1	2	3	4
Model	Baseline	w/ Lag	IV (Sedentariness)	
log(IT Intensity)	0.0300***	0.0308***	0.2857***	0.7923***
	(0.0061)	(0.0059)	(0.0696)	(0.2691)
Log(Non-IT Int.)	0.0007	0.0012	-0.0632**	-0.1529**
	(0.0021)	(0.0020)	(0.0247)	(0.0732)
Log(Emp)	0.3324***	0.3329***	0.7903***	0.7908***
	(0.0153)	(0.0153)	(0.0110)	(0.0138)
Firm FE	Y	Y		
Year FE	Y	Y	Y	Y
Industry FE	Y	Y		Y
R-squared	0.988	0.988	0.3425	0.4008
Observations	~50,000	~50,000	~50,000	~50,000

Panel C: Number of Industries

	1	2	3	4
Model	Baseline	w/ Lag	IV (Sedentariness)	
log(IT Intensity)	0.0109**	0.0107***	-0.2563***	0.4255***
	(0.0043)	(0.0041)	(0.0319)	(0.1312)
Log(Non-IT Int.)	0.0051***	0.0050***	0.2024***	-0.042
	(0.0019)	(0.0018)	(0.0118)	(0.0356)
Log(Emp)	0.1428***	0.1428***	0.3626***	0.3507***
	(0.0084)	(0.0084)	(0.0064)	(0.0078)
Firm FE	Y	Y		
Year FE	Y	Y	Y	Y
Industry FE	Y	Y		Y
R-squared	0.9571	0.9571	0.2198	0.2577
Observations	~50,000	~50,000	~50,000	~50,000

Note: The dependent variables are the logarithm of the number of establishments (Panel A), zip codes (Panel B), and industries (Panel C), respectively. In each panel, column 2 also includes one-year lag of IT intensity and one-year lag of non-IT intensity as controls but are omitted in the table due to space limitations. The IV strategy (columns 3 and 4) in all panels uses the share of sedentary workers at the industry level from 2000 to instrument for IT intensity. *** p<0.01, ** p<0.05, * p<0.1.

Table 8: IT Capital Expenditure and Industry Concentration

	1	2	3	4	5	6
	Δ log(sale HHI)	Δ log(sale CR4)	Δ log(sale top 10%)	Δ log(emp HHI)	Δ log(emp CR4)	Δ log(emp top 10%)
Δ log(IT)	0.080***	0.010***	0.037***	0.084***	0.012***	0.047***
	(0.022)	(0.003)	(0.011)	(0.014)	(0.002)	(0.008)
R-squared	0.015	0.015	0.014	0.042	0.042	0.043
Observations	815	815	815	815	815	815

Note: $\Delta log(IT)$ is the difference of $log(IT)$ between 2004 and 2013. Similarly, the changes in industrial concentration are constructed based on their differences between 2004-2013. Robust standard errors are reported in parentheses;
*** p<0.01, ** p<0.05, * p<0.1.

Appendix

A.1 Stylized Facts in the US Economy

Based on Business Dynamics Statistics (BDS) data from the US Census, the average firm size by employment has been increasing since 1978, as shown in Figure 1. Breaking down the aggregated data into six major sectors, Figure 2 shows that the growth of firm employment has occurred primarily in three sectors: wholesale trade, retail, and service.[21]

To further explore this trend, we evaluate the industrial concentration rate in the private sector from 1976 to 2016 using confidential data from the US Census Bureau.[22] We calculate the employment and sales concentration rates from Revenue-enhanced LBD (LBDRev) at the six-digit NAICS level respectively, then compute the weighted averages of industries within the six major sectors.[23] Figure 3 presents the Concentration Rate 4 (CR4), the share of the largest four firms in the industry, for both employment and sales. Consistent with the findings of earlier studies, over the last four decades, the employment concentration increased in most sectors (except manufacturing).[24] However, the increase in concentration is more pronounced when it is measured by sales. Such a phenomenon is consistent with the "scale without mass" digitization hypothesis (Brynjolfsson et al. 2008). This is true for most sectors including Finance and Real Estate, Wholesale, Services, and even Manufacturing. Additionally, consistent with Autor et al. (2020), these trends for market concentrations are robust when other concentration ratio measures are used

[21]These sectors are 1. Manufacturing, 2.Finance and Real Estate, 3. Utilities and Transportation, 4. Wholesale Trade, 5.Retail Trade, and 6. Services. Please see the detailed definitions of the sectors in Autor et al. (2020), Hsieh and Rossi-Hansberg (2023).

[22]Please see detailed discussion of this data below in section 4.

[23]The weights are calculated using the average employment share of each industry.

[24]Consistently, the evolution of firm size distribution is also evident in the skewness of firm size distribution, especially towards the right tail, as shown in Appendix Figure A1.

(i.e., CR20 and Herfindahl-Hirschman Index (HHI)).[25] We also explore the evolution of the share of top 10% firms, another measure of industrial concentration, as a robustness exercise. The results, shown in Appendix Figure A2, resemble a similar trend displayed in Figure 3. A further validation test indicates that the average change in the logarithmic employment share during this period based on our data is similar to those reported in Hsieh and Rossi-Hansberg (2023).[26]

One particularly interesting pattern is that the sectors with high growth in firm size and industry concentration (i.e., Wholesale, Retail, Services, and Finance and Real Estate) also had the most rapid growth of IT capital investment. As shown in Figure 4, the real total IT investment grew rapidly after 2000 and was more pronounced in the sectors that experienced higher growth in market concentration, implying a positive correlation between the two.[27] In section 6.6, we further examine how the surge of IT in recent years is associated with increases in firm size and industrial concentration using restricted-use firm-level data from the Census Bureau.

In the figures described above, we present the aggregate trend in the U.S. economy with the following stylized facts: (1) average firm size has been growing with respect to both employment and sales, particularly in wholesale trade, retail, and service sectors; (2) market concentration has also increased in those sectors, and is more pronounced in sales than employment; and (3) sectors with faster increases in average sizes and concentration rates are also the ones with faster growth in IT expenditures.

[25]CR20 indicates the concentration ratio of the top twenty firms. HHI is the summation of the squared market share of each firm in the industry. Please see https://www.justice.gov/atr/herfindahl-hirschman-index for more details.

[26]Hsieh and Rossi-Hansberg (2023) calculate the share of the top 10% for consistent four-digit SIC codes. Our paper makes use of time-consistent six-digit NAICS codes provided by Fort and Klimek (2016).

[27]We calculate the total IT capital investment by summing the capital investments for all IT equipment and software categories including mainframes, PCs, DASDs, printers, terminals, tape drives, storage devices, system integrators, prepackaged software, custom software, and own-account software using the private asset investment series between 1977 and 2018 from the Bureau of Economic Analysis. Our figure is based on the data updated on September 2, 2020. The data can be accessed from https://apps.bea.gov/national/FA2004/Details/Index.htm.

A.2 Proof of Proposition 1

The proof is based on the work of Max R. P. Grossmann on computing the asymmetric Cournot equilibrium with linear demand which is available here. The first-order condition of profit 2 with respect to q_{ijt} leads to:

$$-b_j q_{ijt} + A_j - b_j Q_{jt} - \tilde{c}_{ijt} = 0.$$

From this condition, we can derive that for the output schedule of each firm i and all its competitors in city j and time t the following condition holds:

$$2b_j q_{ijt} + b_j \sum_{l \neq i} q_{ljt} = A_j - \tilde{c}_{ijt}.$$

Essentially, we have n_{jt} such conditions of each firm that is active in city j in period t. Let

$$\mathbf{q}_{jt} = \begin{pmatrix} q_{1jt} \\ q_{2jt} \\ \cdot \\ \cdot \\ \cdot \\ q_{n_{jt}jt} \end{pmatrix}, \quad \mathbf{M}_{jt} = b_j \begin{pmatrix} 2 & 1 & \cdots & 1 \\ 1 & 2 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 1 \\ 1 & \cdots & 1 & 2 \end{pmatrix}, \quad \mathbf{R}_{jt} = \begin{pmatrix} A_j - \tilde{c}_{1jt} \\ A_j - \tilde{c}_{2jt} \\ \cdot \\ \cdot \\ \cdot \\ A_j - \tilde{c}_{n_{jt}jt} \end{pmatrix},$$

where, $\mathbf{M}_{jt}$ is a $n_{jt} x n_{jt}$ matrix. Then, these n_{jt} conditions can be re-written in a matrix form as

$$\mathbf{M}_{jt}\mathbf{q}_{jt} = \mathbf{R}_{jt}.$$

Then, the matrix of the Cournot equilibrium outputs $\mathbf{q}_{jt}$ equals

$$\mathbf{q}_{jt} = \mathbf{M}_{jt}^{-1}\mathbf{R}_{jt},$$

where,

$$\mathbf{M}_{jt}^{-1} = \frac{1}{b_j(n_{jt}+1)} \begin{pmatrix} n_{jt} & -1 & . \quad . \quad . & -1 \\ & & . & . \\ -1 & n_{jt} & . & . \\ & & . & . \\ . \quad . & & . & \\ . & . & . & -1 \\ . & . & . & \\ -1 \quad . \quad . \quad . & & -1 & n_{jt} \end{pmatrix}$$

By multiplying $\mathbf{M}_{jt}^{-1}$ and $\mathbf{R}_{jt}$ after some algebraic manipulations we arrive to the Cournot equilibrium output (4) for each firm i, in city j and period t.

A.3 Proof of Corollary 1

It immediately follows from the marginal effects of $\tilde{c}_{ijt}$ on q_{ijt}^* and Q_{jt}. From Cournot equilibrium (4), we have: $\frac{\partial q_{ijt}^*}{\partial \tilde{c}_{ijt}} = -\frac{n_{jt}}{b_j(n_{jt}+1)} < 0$ and $\frac{\partial Q_{jt}^*}{\partial \tilde{c}_{ijt}} = \frac{n_{jt}-1}{b_j(n_{jt}+1)} - \frac{n_{jt}}{b_j(n_{jt}+1)} = \frac{-1}{b_j(n_{jt}+1)} < 0$. In the latter expression, the term $\frac{n_{jt}-1}{b_j(n_{jt}+1)}$ refers the strategic effect of firm i's IT investment on aggregate output and the term $\frac{n_{jt}}{b_j(n_{jt}+1)}$ refers to the direct effect of firm i's IT investment aggregate output. These two effects are opposite in sign. As firm i invests more on IT capital, its competitors in city j produce less output and firm i produces more output. The overall impact of IT investment on aggregate output is positive because from these two opposite effects, it is the direct effect that dominates over the marginal impact of IT investment on aggregate output.

An IT investment advantage for firm i implies that firm i has a lower marginal cost in comparison to the average marginal cost of its competitors. Following expression (4), this means that firm i has in equilibrium a higher output level.

A.4 Proof of Proposition 2 and Corollary 2

As firm i is active in more cities, the second and fourth terms in total profit (3) admit higher values. Since these two firms have opposite signs, it is their comparison that determines in how many cities firm j decides to be active in each period t. Firms decide to be active in the number of cities that maximize total profit (3) evaluated at the Cournot equilibrium of output (4) and per city profit (5). This is true only by adding an additional city l, the additional profit π_{ilt} is greater than the additional overhead cost from operating in one more city. Firm i which currently finds it profitable to operate in N_{it} cities, will find it profitable to expand into an additional city l, thus operating in $N_{it}+1$ cities in total only if:

$$\Pi^*_{it}(N_{it}+1) - \Pi^*_{it}(N_{it}) > 0 \Rightarrow \pi^*_{ilt} > \Psi(N_{it}+1) - \Psi(N_{it}).$$

The optimal number of cities firm i is active in is the lowest number of cities N^*_{it} for which this condition does not hold. It should also be $\Pi^*_{it}(N_{it}) - \Pi^*_{it}(N_{it}-1) > 0$ which ensures that N^*_{it} is the maximum number of cities at which firm i finds it profitable to operate.

As π^*_{ilt} is strictly increasing in firm i's IT investment, from the above conditions, the optimal number of cities N^*_{it} is also increasing with IT investment.

A.5 Proof of Lemma 1

It is

$$l^*_{ijt} = \frac{\tilde{c}_{ijt}}{b_j w} \frac{A_j + \sum_{y \neq i} \tilde{c}_{yjt} - n_{jt}\tilde{c}_{ijt}}{n_{jt} + 1}.$$

So,

$$\frac{\partial l^*_{ijt}}{\partial \tilde{c}_{ijt}} = \frac{A_j + \sum_{y \neq i} \tilde{c}_{yjt} - n_{jt}\tilde{c}_{ijt}}{b_j w(n_{jt}+1)} - \frac{n_{jt}\tilde{c}_{ijt}}{b_j w(n_{jt}+1)} = \frac{A_j + \sum_{y \neq i} \tilde{c}_{yjt} - 2n_{jt}\tilde{c}_{ijt}}{b_j w(n_{jt}+1)}.$$

If IT capital and labor are complements, it is $\frac{\partial l^*_{ijt}}{\partial \tilde{c}_{ijt}} < 0$, the condition (6) follows immediately. The opposite holds when IT capital and labor are substitutes.

A.6 Proof of Corollary 3

Following the definition of l^*_{ijt}, the labor share of production of firm i in city j and in period t is

$$\lambda^*_{ijt} = \frac{l^*_{ijt}}{q^*_{ijt}} = \frac{\tilde{c}_{ijt}}{w}.$$

So, $\frac{\partial \lambda^*_{ijt}}{\partial \tilde{c}_{ijt}} > 0$, which implies that λ^*_{ijt} is strictly declining in firm i's IT investment.

A.7 Proof of Corollary 4

From the definition of α^*_{ijt} and the proof of Corollary 1, it is easy to see that:

$$\frac{\partial \alpha^*_{ijt}}{\partial \tilde{c}_{ijt}} = \frac{-n_{jt}Q^*_{jt} + q^*_{ijt}}{b_j(n_{jt}+1)(Q^*_{jt})^2} < 0.$$

Moreover,

$$\frac{\partial^2 \alpha^*_{ijt}}{\partial(\tilde{c}_{ijt})^2} = \frac{\left(\frac{n_{jt}}{b_j(n_{jt}+1)} - \frac{n_{jt}}{b_j(n_{jt}+1)}\right) b_j(n_{jt}+1)Q_{jt} + 2(-n_{jt}Q^*_{jt} + q^*_{ijt})Q^*_{jt}}{b_j^2(n_{jt}+1)^2(Q^*_{jt})^4} = 2\frac{-n_{jt}Q^*_{jt} + q^*_{ijt}}{b_j^2(n_{jt}+1)^2(Q^*_{jt})^3} < 0$$

Firm i's IT investment increases its own market share. The relationship between IT investment and firm i's market share becomes steeper as IT investment increases.

In order to derive the implications of firm i's IT investment for the market concentration index, $HHI^*_{jt}*$, we also need to evaluate how firm i's IT investment affects the market shares of its competitors. The output of a competitor firm m is affected by firm i's IT investment as:

$$\frac{\partial q^*_{mjt}}{\partial \tilde{c}_{ijt}} = \frac{1}{b_j(n_{jt}+1)} > 0.$$

Consequently, m's market share is affected by firm i's IT investment as:

$$\frac{\partial a^*_{mjt}}{\partial \tilde{c}_{ijt}} = \frac{Q^*_{jt} + q^*_{mjt}}{b_j(n_{jt}+1)Q^*_{jt}} > 0.$$

Firm i's IT investment leads to the decline of the market share of each competitor m in market j.

So, firm i's IT investment increases its own market share (direct effect) but decreases the market shares of its competitors (strategic effect). Hence, the overall impact of firm i's IT investment on HHI^*_{jt} depends on which of these two effects dominate. We have already found that the direct effect is more pronounced for higher market shares. For the strategic effect we have:

$$\frac{\partial^2 a^*_{mjt}}{\partial(\tilde{c}_{ijt})^2} = \frac{Q^*_{jt} + q^*_{mjt}}{b_j^2(n_{jt}+1)^2 Q^*_{jt}} > 0.$$

So, the marginal effect of firm i's IT investment on the market share of competitor, m is greater when i is relatively inefficient and has a low market share.

Intuitively, we can then expect that the direct effect of IT investment on market j's concentration will be the dominant one when firm i has sufficiently high market share. We have:

$$\frac{\partial HHI^*_{jt}}{\partial \tilde{c}_{ijt}} = \frac{\partial}{\partial \tilde{c}_{ijt}} \left(\sum_{m \neq i} \left(\frac{q^*_{mjt}}{Q^*_{jt}} \right)^2 \right) + \frac{\partial}{\partial \tilde{c}_{ijt}} \left(\frac{q^*_{ijt}}{Q^*_{jt}} \right)^2 .$$

The first term in the right-hand side is the total strategic effect over all competitors in city j:

$$\frac{\partial}{\partial \tilde{c}_{ijt}} \left(\sum_{m \neq i} \left(\frac{q^*_{mjt}}{Q^*_{jt}} \right)^2 \right) = \sum_{m \neq i} \frac{\partial}{\partial \tilde{c}_{ijt}} \left(\frac{q^*_{mjt}}{Q^*_{jt}} \right)^2 = \frac{2\sum_{m \neq i} q^*_{mjt}}{b_j(n_{jt}+1)(Q^*_{jt})^2} + \frac{2\sum_{m \neq i}(q^*_{mjt})^2}{b_j(n_{jt}+1)(Q^*_{jt})^3} > 0.$$

The other term refers to the direct effect which is:

$$\frac{\partial}{\partial \tilde{c}_{ijt}} \left(\frac{q^*_{ijt}}{Q^*_{jt}} \right)^2 = 2\frac{-n_{jt}Q^*_{jt} + q^*_{ijt}}{b_j(n_{jt}+1)(Q^*_{jt})^2} \frac{q^*_{ijt}}{Q^*_{jt}} < 0.$$

So, firm i's IT investment can increase market concentration ($\frac{\partial HHI^*_{jt}}{\partial \tilde{c}_{ijt}} < 0$) when the direct effect dominates or it can decrease market concentration ($\frac{\partial HHI^*_{jt}}{\partial \tilde{c}_{ijt}} > 0$) when the strategic effect dominates.

Note that $\sum_{m \neq i} q^*_{mjt} = Q^*_{jt} - q^*_{ijt}$ and that $\sum_{m \neq i}(q^*_{mjt})^2 < (Q^*_{jt})^2$. Then, a sufficient (but not necessary) condition for the direct effect to dominate is:

$$\frac{2(Q^*_{jt} - q^*_{ijt})}{b_j(n_{jt}+1)(Q^*_{jt})^2} + \frac{2(Q^*_{jt})^2}{b_j(n_{jt}+1)(Q^*_{jt})^3} - 2\frac{-n_{jt}Q^*_{jt} + q^*_{ijt}}{b_j(n_{jt}+1)(Q^*_{jt})^2}\frac{q^*_{ijt}}{Q^*_{jt}} < 0 \Rightarrow \frac{q^*_{ijt}}{Q^*_{jt}} > \frac{2}{n_{jt}+1}.$$

So, we conclude that if in city j and in period t firm i's market share is sufficiently high, firm i's IT investment rises market concentration in city j.

A.8 Proof of Proposition 3

It immediately follows from the first-order condition over total profit (3) with respect to IT investment φ_{it}.

A.9 Skewness of Firm Employment Distribution

The evolution of firm size distribution is evident not just in average firm size but also in skewness, especially towards the right tail. Figure A1 presents the changes in the skewness of firm employment from 1987 to 2012 using micro-level census data.[28] In Trade, Transportation, Arts, Accommodation, Information and Finance, and Other service sectors, firm employment distribution is more skewed towards larger firms - a trend that suggests a more concentrated market. On the other hand, the manufacturing sector shows a declining skewness and, thus, a declining industrial concentration.[29]

[28]This is similar to the one presented in Benzel & Brynjolfsson (2021).

[29]Trade, Transportation, Arts, Accommodation, and Other services include sectors from NAICS 42, 44-45, 71, 72, 81; Information and Finance includes NAICS 51 and 52.

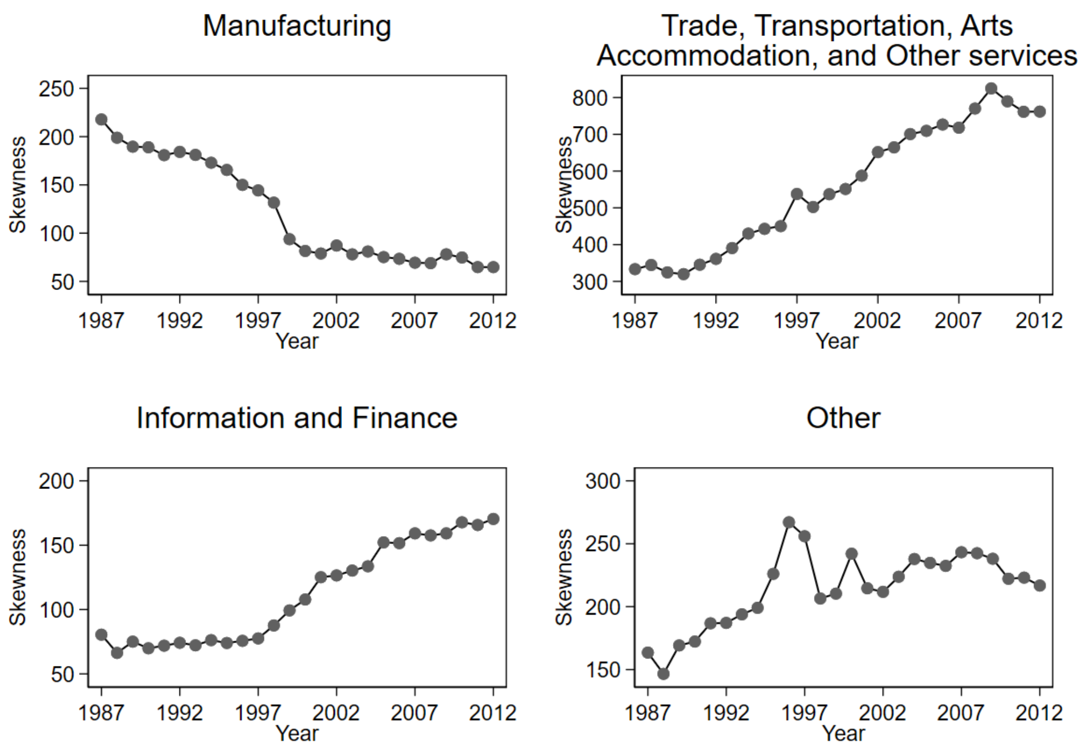


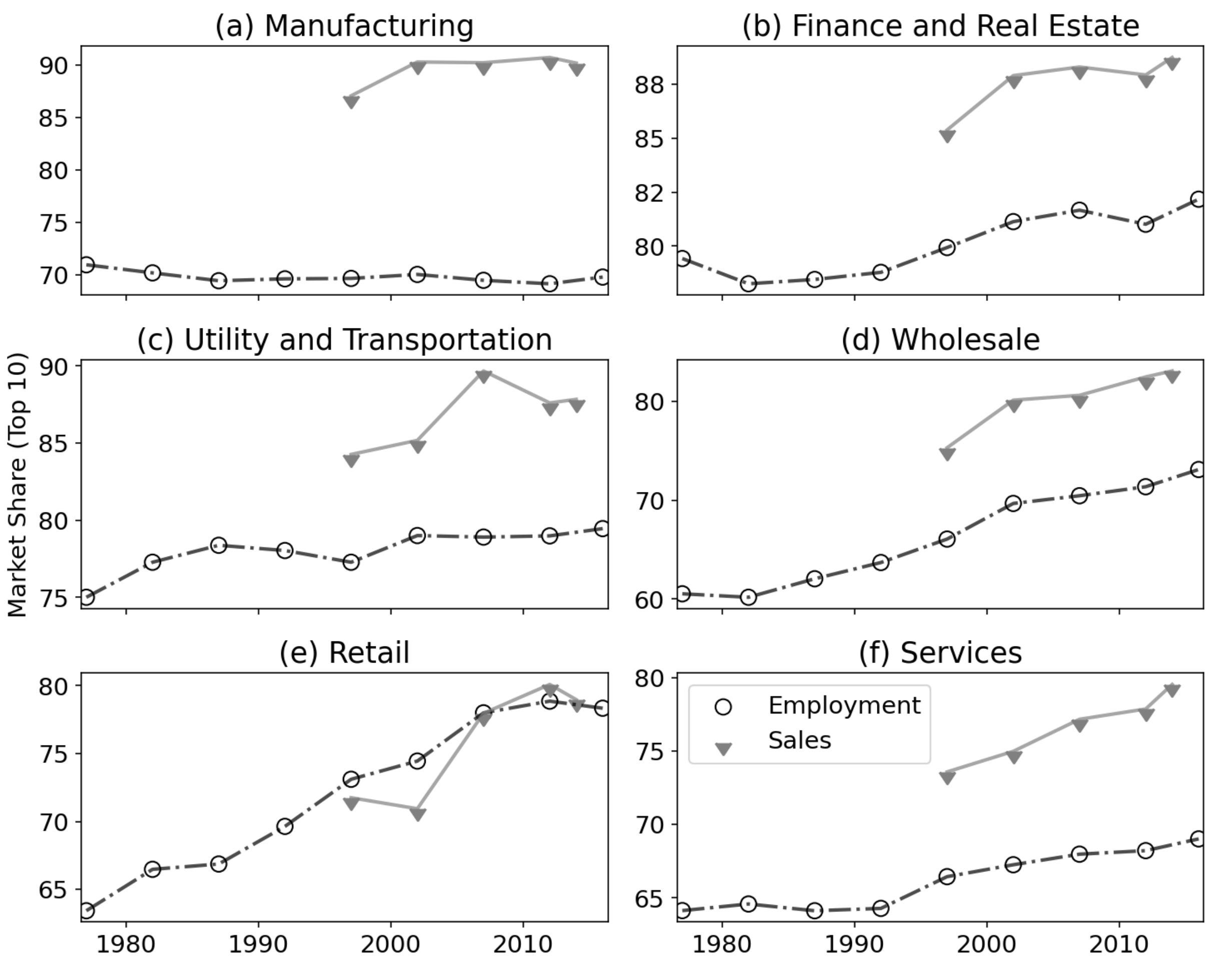
Figure A1: Skewness of Firm Employment Distribution by Major Sectors (1987-2012)

Note: Based on the Longitudinal Business Database (LBD). From Benzell & Brynjolfsson (2021). Manufacturing: NAICS 31-33; Trade, Transportation, Arts, Accommodation, and Other Services: NAICS 42, 44-45, 71, 72, 81; Information and Finance: NAICS 51, 52.

A.10 Share of Top Ten Percent Firms

Following Hsieh and Rossi-Hansberg (2023), we present the evolution of the share of the top 10% firms in six major sectors as an additional measure of the industrial concentration. Figure A2 shows trends similar to Figure 3 that is, Finance and Real Estate (b), Wholesale (d), Retail (e), and Services (f) sectors present an increasing share from the top 10% firms. And it is true for both employment and sales. To compare with Hsieh and Rossi-Hansberg (2023), we calculate the average change of log employment share during this period and find similar results. [30]

[30]In Hsieh and Rossi-Hansberg (2023), one major difference is that they calculate the share of top 10% for consistent four-digit SIC codes while we make use of six-digit FK NAICS codes. Moreover, we have both the changes in sales and employment while they focus on the change of log employment share only.



(a)

Figure A2: Employment and Sales Concentration Rates for Top 10 Percent Firms

Note: We follow a method similar to Hsieh and Rossi-Hansberg (2023) to calculate the share of the top 10% firms in each industry and take the weighted average to the sector level. The definition of sectors is consistent with the definition in Figure 3.

A.11 Key IT Measures in the ACES and ICTS

ACES Data Item Description:

- Item 2 - Total capital expenditures
- Item 5 - Capitalized Computer Software
  - Prepackaged
  - Vendor-customized
  - Internally-developed

Please see details of ACES questionnaires at:https://www.census.gov/programs-surveys/aces/technical-documentation/questionnaires.html

ICTS Data Item Description

- Item 2, Equipment Expenditures
  - 311: Computer and Peripheral Equipment
  - 313: Information and Communication Technology Equipment, Excluding Computer and Peripheral Equipment
  - 316: Electromedical and Electrotherapeutic Apparatus
- Item 3, Computer Software Expenditures
  - Capitalized Purchases and Payroll for Developing Software
  - Non-capitalized Purchases and Payroll for Developing Software

– Non-capitalized Software Licensing and Service/Maintenance Agreements

Please see details of ICTS questionnaires at: https://www.census.gov/programs-surveys/icts/technical-documentation/questionnaires.html

A.12 Alternative Instrumental Variable Specification

In addition to the IV strategy using the industry-level share of sedentary workers, we follow Barth et al. (n.d.) and adopt lagged IT investment from two years ago to instrument current IT investment. The results are presented in Table A1. Consistent with Table 5, IV estimations reveal a statistically significant correlation between IT and sales, but no corresponding association with employment. Similar to Table 5, a one percent increase in IT intensity is associated with about a 0.6 to 0.8 percent increase in sales. These results help further strengthen the causal relation between IT and sales as previously presented in Section 6.

A.13 Robustness Check with IT Expenditure

In addition to the results in Section 6, we also use IT expenditure as an alternative measure for robustness checks. We follow the empirical method in equation 7. The independent variables are the logarithm of the IT expenditures and non-IT expenditures and we report the results from these specifications in Table A2. The results show that IT expenditure is positively associated with firms' sales, employment, and their corresponding industrial shares, but negatively associated with firms' labor share. These results are broadly consistent with our main findings reported above.

To compare how IT investment is associated with sales versus employment, we present Table A3, where both outcomes are measured contemporaneously with the right-hand-side variables. The

Table A1: Instrumental Variable Models
Two Year Lagged IT Intensity

Dep.Var.	Sales		Employment (t+1)	
	1	2	3	4
log(IT Intensity)	0.780***	0.643***	-0.004	0.009
	(0.021)	(0.023)	(0.004)	(0.006)
log(Non-IT Intensity)	0.282***	0.168***	0.017***	0.025***
	(0.011)	(0.009)	(0.002)	(0.002)
Log(Emp)	0.952***	0.942***	0.985***	0.979***
	(0.009)	(0.008)	(0.002)	(0.002)
1st Stage coefficient	0.772***	0.682***	0.818***	0.748***
	(0.008)	(0.010)	(0.007)	(0.008)
KP Chi-sq	703.6	621.2	718.4	645.8
CD Wald F	46970	28210	69180	43960
KP Wald F	8758	5053	15840	8653
Year FE	Y	Y	Y	Y
Industry FE		Y		Y
R-squared	0.679	0.705	0.956	0.949
Observations	~35,000	~35,000	~35,000	~35,000

Note: We use lagged IT investment from two years ago to instrument current IT investment. The number of observations is rounded to the nearest thousand, in accordance with Census Bureau disclosure rules. Robust standard errors are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

estimated coefficients indicate a larger elasticity of sales than of employment with respect to IT.

Table A2: IT Expenditure, Firm Size, Market Share, and Labor Share

Dep.Var.	Sales				Employment			
	1	2	3	4	5	6	7	8
log(IT Expnd)	0.0269***	0.0241***	0.0195***	0.0193***	0.0187***	0.0159***	0.0154***	0.0148***
	(0.0023)	(0.0022)	(0.0022)	(0.0021)	(0.0015)	(0.0015)	(0.0015)	(0.0014)
log(IT Expnd)(t-1)		0.0156***	0.0149***	0.0148***		0.0154***	0.0155***	0.0147***
		(0.0024)	(0.0024)	(0.0024)		(0.0015)	(0.0015)	(0.0015)
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE		Y	Y	Y			Y	Y
Industry FE			Y	Y				Y
R-squared	0.9611	0.9623	0.9628	0.9722	0.9593	0.9597	0.9598	0.9623
Observations	~50,000	~50,000	~50,000	~50,000	~50,000	~50,000	~50,000	~35,000

Note: The independent variables are the logarithm of the IT expenditures and non-IT expenditures. Firm's sales share is calculated as the share of firm's sales in the total sales of the six-digit NAICS industry. Firm's employment share is calculated as the share of the firm's employment in the total employment of the six-digit NAICS industry. Labor share is calculated as the ratio of payroll to sales of the firm. The number of observations is rounded to the nearest thousand, in accordance with Census Bureau disclosure rules. Robust standard errors are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

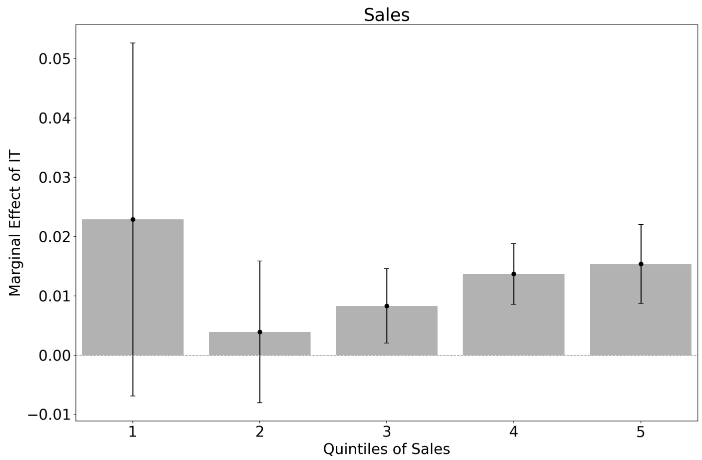
Table A3: IT Expenditure with Sales and Employment

Dep.Var.	Sales				Employment			
	1	2	3	4	5	6	7	8
log(IT Expnd)	0.0269***	0.0241***	0.0195***	0.0193***	0.0187***	0.0159***	0.0154***	0.0148***
	(0.0023)	(0.0022)	(0.0022)	(0.0021)	(0.0015)	(0.0015)	(0.0015)	(0.0014)
log(IT Expnd)(t-1)		0.0156***	0.0149***	0.0148***		0.0154***	0.0155***	0.0147***
		(0.0024)	(0.0024)	(0.0024)		(0.0015)	(0.0015)	(0.0015)
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE		Y	Y	Y			Y	Y
Industry FE			Y	Y				Y
R-squared	0.9611	0.9623	0.9628	0.9722	0.9593	0.9597	0.9598	0.9623
Observations	~50,000	~50,000	~50,000	~50,000	~50,000	~50,000	~50,000	~35,000

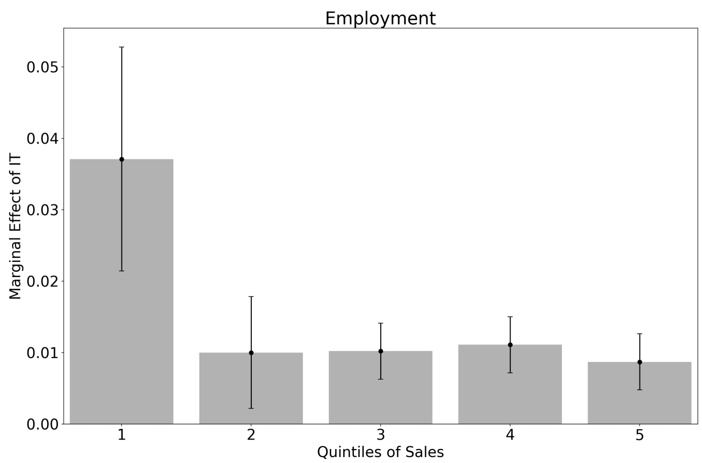
Note: We use both simultaneous and lagged IT investment as the right-hand side variable. Firm, industry, and year fixed-effects are included in the specifications for columns 4 and 8 (as some firms changed their main industries over time). The number of observations is rounded to the nearest thousand, in accordance with Census Bureau disclosure rules. Robust standard errors are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Heterogeneous Effects of IT Expenditure on Firm Size by Size Category

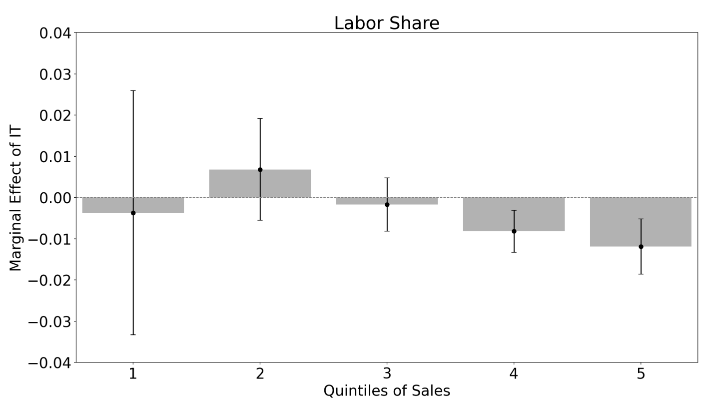
Similar to Figure 5, we follow equation 8 in section 5 and explore the effect heterogeneity of IT expenditure (instead of IT intensity) for different-sized firms for an additional robustness check. The marginal effects of IT expenditure on sales, employment, and labor share are plotted in Figure A3 Panel (a), (b), and (c), respectively. The results are largely consistent with Figure 5 and provide additional supporting evidence that investment in IT is associated with a faster growth of sales and employment, and a faster decline of labor share for larger firms, which then further suggest that IT contributes to the growing industrial concentration.



(a)



(b)



(c)

Figure A3: Heterogeneous Returns of IT Expenditure on Firm Size by Size Category

Note: This figure presents the estimated marginal effects of IT expenditure on firm sales (Panel a), employment (Panel b), and labor share (Panel c). Quintiles are based on sales distribution. Vertical lines represent the 95% confidence intervals.