# Information Technology, Firm Size, and Industrial Concentration*

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**Abstract**

Information flows — and information technology (IT) that enable them — are central to the organization of firms and the structure of markets. In this paper, we develop a Cournot competition model to identify three interrelated mechanisms through which IT investment shapes firm size and market shares. Using firm-level data from the U.S. Census Bureau, we provide empirical evidence that greater IT intensity is associated with increases in firm size and market concentration, measured by both employment and sales. Results from instrumental variables and long-difference models suggest that the identified effect is likely causal. The effect of IT is more pronounced on sales than employment, leading to a decline in the labor share, consistent with the "scale without mass" theory of digitization. We also find that IT disproportionately benefits larger firms by enhancing their capability to scale and replicate their operational processes across multiple establishments, markets, and industry segments. These results suggest that the substantial rise in IT investment is one of the key driving forces behind the growth of firm size, the emergence of superstar firms, declining labor share, and rising market concentration in recent years.

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# 1 Introduction

Advances in information technology (IT)–along with large declines in costs of storing, transferring, and analyzing digital information–have reshaped modern economies and societies (Brynjolfsson and McAfee 2014). Because firms and markets are fundamentally information-processing systems (Hayek 1945, Galbraith 1974, Sah and Stiglitz 1986), the rapid diffusion of IT and the sharp declines in its cost are likely to profoundly transform how the economic activities are organized. This paper examines how investment in IT affects firm size, measured by employment, revenue, and market share, and how, and explores the extent to which IT has contributed to the rise of market concentration in the United States.

Earlier theories linked IT adoption to changes in organizational structure (e.g., Brynjolfsson and Mendelson 1993, Brynjolfsson and Hitt 1998, Malone and Rockart 1991, Bloom et al. 2014) broadly and firm size in particular (e.g., Gurbaxani and Whang 1991, Brynjolfsson et al. 1994). One prominent channel is automation and labor substitution: IT can replace routine tasks in production, reducing the need for human labor and thus leading to a smaller average firm size in employment (e.g., Dewan and Min 1997). A second channel is output expansion: it can enhance firms' ability to scale production, reach more custmers, and increase sales-potentially raising aggregate employment and firm size (e.g., Tambe and Hitt 2012, Acemoglu et al. 2018).

A third theoretical channel involves organizational design and the allocation of decision rights. IT can also reduce the costs of information transfer and monitoring, improve decision-making, and enhance overall efficiency through either moving information to decision-makers or moving decision rights to information (Brynjolfsson and Mendelson 1993). Because decision rights are tied to property rights and boundaries of the firm (Garicano 2000, Grossman and Hart 1986, Hart and Moore 1990, Jensen and Meckling 1976), IT may shift the relative balance between market transactions and in-house coordination, affecting the extent of vertical integration or outsourcing (Gurbaxani and Whang 1991).

Taken together, these channels suggest that the net effect of IT on firm size is theoretically

ambiguous and depends on which mechanisms dominate. For example, if labor substitution outweighs the gains from scale and coordination, IT may reduce firm size. Conversely, if scale economies and coordination efficiencies prevail, IT can facilitate the growth of larger, more complex organizations.

Empirical evidence from earlier decades supports the former view. Several studies documented a negative correlation between IT and firm size, suggesting automation and reduction in market transaction costs were the dominant effects. For instance, Brynjolfsson et al. (1994) showed that IT investment was associated with the decline in the average size—both employment and sales using—using industry-level data from 1976 to 1989. Similarly, Hitt (1999) and Im et al. (2013) found that increased IT use reduced vertical integration and encouraged reliance on external markets.

However, more recent administrative data from the US reveal a reversal of this trend: average firm size increased significantly (Figure 1), especially in Finance and Real Estate, Wholesale, Retail, and Services sectors (Figure 2). This expansion has been accompanied by sharp increases in market concentration[1] (Figure 3) for the corresponding sectors. As the economy expands, this implies firms already at the top of the size distribution tend to scale disproportionately quickly, accentuating the skew in firm sizes (Hsieh and Rossi-Hansberg 2019, Autor et al. 2020). Industry-level studies reinforce this picture: IT-intensive sectors exhibit particularly uneven growth, with leading incumbents pulling further ahead after adopting advanced digital technologies (Bessen 2020).

Lashkari et al. (2024) further provide a key theoretical insight into this shift. They show that IT demand is non-homothetic: larger firms adopt IT more intensively and disproportionately benefit from falling IT prices. This inherent scale bias increases firm-level returns to scale and contributes to aggregate trends in concentration and labor share. Their quantitative model, calibrated on French firm-level data, accounts for a significant share of the observed rise in industry concentration and

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

changes in the labor share.

Moreover, Autor et al. (2020) emphasize that increased industrial concentration and the rise of superstar firms are closely linked to the declining labor share in the US economy. Sector-specific evidence supports this pattern—for example, in retail sector, where large national chains such as Walmart have grown more rapidly than smaller firms in recent years (Foster et al. 2016). These shifts have raised broader concerns about their macroeconomic and social consequences, including slower innovation, declining business dynamism, and rising inequality, drawing increasing attention from both researchers and policymakers.

Meanwhile, IT adoption has surged precisely in the sectors experiencing the greatest increases in firm size and concentration (Figure 4). Anecdotal evidence further support that IT may be a major driver of the increased firm size and market concentration. For instance, 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).[2] Similarly, CVS leveraged IT to standardize and scale not only data and software but also business processes (McAfee and Brynjolfsson 2008).

Another striking example of the IT transformation is the growing prevalence of private equity–backed roll-up strategies (Baik et al. 2024), in which IT systems are used to centralize and replicate operations across numerous small acquisitions in fragmented markets such as healthcare, logistics, and business services.[3] These strategies rely on IT not only for efficiency and oversight but also for codifying processes and enabling scalable expansion—illustrating how digital infrastructure facilitates firms to scale up through organizational replication and market entry.

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

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

These examples illustrate how IT-characterized by high-fixed-cost-low-variable-cost-naturally favors larger firms and reinforces increasing return to scale (Tambe and Hitt 2012, Feigenbaum and Gross 2021). In addition, larger firms typically have more complementary organizational capabilities needed to fully exploit IT investment (Tambe et al. 2020), further magnifying the effect of IT(Brynjolfsson and Milgrom 2012, Brynjolfsson et al. 2021b).

A growing body of research has begun to formalize the connection between the surges of IT and rising market concentration (Hsieh and Rossi-Hansberg 2019, Aghion et al. 2019, De Ridder 2024, Lashkari et al. 2024). Yet, despite these advances, large-scale firm-level evidence remains scarce—limiting our understanding of how different firms adopt and benefit from IT, and which mechanisms drive the observed shifts in firm size and market structure.

This paper develops a theoretical model based on Cournot competition of firms, each of which rely on labor and IT capital for producing its output. The model studies the different channels and mechanisms through which IT investment affects firms' production decisions and size, deriving theoretical predictions that motivate the empirical investigation. We use detailed micro-level data on a representative sample of U.S. firms based on the administrative records from the U.S. Census Bureau. To capture the broad impact of IT as a general-purpose technology (GPT), our preferred measure is the total IT capital investment. Furthermore, we examine how this relationship varies across firms and sectors, contributing to the broader trend of rising market concentration in recent decades.

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 transfer knowledge from its most efficient units to others, reducing marginal cost of production. We identify three interrelated mechanisms through which IT investment affects firm size: (1) improving average production efficiency, (2) expanding output and market share, and (3) enabling firms to enter more local markets by establishing new business units. These effects vary by firm size, market share, and IT intensity.

Empirically, our main findings suggest that investment in IT is strongly associated with greater sales and market shares in recent decades. These results are robust to various specifications, fixed-effects, sample weights, and alternative IT measures. Using long-difference estimations and instrumental variable strategies following prior literature (Brynjolfsson and Mendelson 1993, Bessen 2020), we show that our results are consistent. This suggests that the positive relationship between IT and firms' revenue is likely causal. By contrast, the employment effects of IT investment are less robust. Although both OLS and long-difference estimates yield a positive association, the effect disappears when we instrument for IT, implying that—once endogeneity is addressed—firms can expand sales without a commensurate increase in headcount. This pattern is emblematic of "scale without mass" Brynjolfsson et al. (2008).

Additional mechanism tests reveal that the effects of IT on firm size 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.

Our study builds on this insight but makes two distinct contributions. First, we develop a new theoretical framework that isolates multiple mechanisms—output expansion, production efficiency, and network scale—through which IT investment affects firm size, labor share, and concentration. Through these mechanisms, our model derives new insights and empirical predictions that point towards to the differential impact of IT on firms with different size and market share. Second, we empirically test these predictions using a comprehensive firm-level database in the U.S., allowing us to disentangle competing effects and identify causal pathways. By focusing on endogenous investment behavior and the role of firm characteristics, we offer a complementary and novel perspective on the link between IT investment and industrial concentration.

Recent advances in artificial intelligence (AI) promise similarly far-reaching consequences. By raising labor productivity, AI lets firms expand revenue without enlarging their workforces

proportionally. Large incumbents stand 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. As a result, the diffusion of AI is likely to reinforce—and perhaps accelerate—the ongoing rise in market concentration.

The rest of this paper is organized as follows. Section 2 discusses relevant contributions and walks through some related empirical studies and their finds; section 3 presents stylized facts in the US economy; section 4 develops our theoretical model and the main empirical predictions that motivate our empirical study; section 5 describes the data used for this study; section 6 introduces the empirical methods; section 7 presents the empirical findings; and section 8 concludes.

# 2 Literature Review

## 2.1 Costs of Information Transfer and Firm Size

In his classic paper, Hayek (1945) points out that information and knowledge are dispersed among all actors who participate in economic activities. Thus, decisions should be made by the person with information concerning particular circumstances of time and place for efficiency gain. Because a firm can be viewed as a nexus of contracts among self-interested individuals, within which conflicts of interest may occur (Jensen and Meckling 1976), the decision right should be accompanied by information and knowledge to maximize efficiency.

Moreover, these contracts are often ambiguous and incomplete, creating an important role for residual rights of control based on asset ownership. A well-designed incentive system will allocate decision rights in part via control of these assets (Grossman and Hart 1986). The costs of transferring and processing knowledge thus play a significant role in deciding the allocation of both property and decision rights and thereby the boundaries between firms and markets. Built on this line of thoughts, Brynjolfsson and Mendelson (1993) propose that, depending on the cost of information transmission and processing, matching decision rights can be achieved either by

the information system solution (moving information to the decision-maker) or by the organization redesign solution (moving decision rights to information).

These have immediate and significant implications on firm sizes as widely dispersed information and knowledge should lead to decentralized decision-making and smaller firms, and vice versa (Garicano 2000). IT can reduce the costs of collecting, processing, and transferring information and knowledge. This not just enables the acquisition of dispersed knowledge and facilitates remote monitoring but also lowers the cost of information transfer to delegated decision-makers. In both scenarios, IT leads to better decision-making and improve efficiency for firms but can lower costs of coordination both internally and externally, leading to an ambiguous prediction of its impact on firm size from this lens.

Several papers note that the boundary and structure of the firm depend on the relativity of the effects of IT on transaction and coordination costs. Malone et al. (1987) argue that the overall effect of IT in reducing both the internal and external coordination costs should generally shift economic activities towards markets rather than hierarchies. Similarly, Clemons et al. (1993) argue that a lowered inter-firm coordination cost would encourage firms to outsource with a smaller set of stable partners without acquiring their ownership. Through the property right lens, Brynjolfsson (1994) argues that IT leads to reduced integration and, thus, smaller firms as: (1) it improves worker's information and therefore provides further incentives; (2) it leads to less lock-in in the use of physical assets; or (3) it enables decentralized coordination and reduces centralized coordination.

Early empirical studies did find that IT generally led to smaller firms on average. Brynjolfsson et al. (1994), who combine multiple data sources at the industry level, find that IT investment has been associated with subsequent decreases in the average size of firms using data from 1976 to 1989. Several other papers using micro-level data also found a negative relationship between IT investment and firm size during the 1980s and early 1990s. They attributed their findings to a reduced coordination cost between firms Im et al. (2001, 2013). Hitt (1999) further investigates the firm structure of 549 large public firms and concludes that the increased use of IT substantially decreases firms' vertical integration and favors external procurement.

On the other hand, IT can result in more integration and larger firms if its effect on internal coordination costs becomes more pronounced. This seems to be increasingly important in the last two decades, given the diffusion of information systems such as Enterprise Resource Planning (ERP), inventory, accounting, and HR management systems which allow low-cost firm-wide information sharing and transfer. Advances in cloud computing further enable ubiquitous intra-firm information access among all business units, reducing the cost of coordination. In conjunction with network externalities and economies of scale, IT will tend to support centralized ownership of assets, and hence larger firm size. The growth of "superstar" firms, documented by Autor et al. (2020), Covarrubias et al. (2020), Hsieh and Rossi-Hansberg (2019), as well as some empirical studies focusing on the retail sector (Basker et al. 2012, Doms et al. 2004, Foster et al. 2016, Hortaçsu and Syverson 2015), is consistent with the hypothesis that this mechanism has become more important in recent decades. Relatedly, Aghion et al. (2019) propose that accelerating IT advances lead to the falling firm-level costs of entering multiple markets, and, thereafter, become the driving force behind a series of economic phenomena including expanding firm boundaries, increasing markups, declining labor share, and rising industrial concentration.

Meanwhile, Empirical studies further illuminate this dynamic. Giroud and Mueller (2019) demonstrate that firms' internal networks facilitate the propagation of local economic shocks across regions. Their analysis reveals that establishment-level employment is sensitive to shocks in distant regions where the parent firm operates, indicating that firms actively reallocate resources among their establishments to optimize performance in response to localized disturbances. This capacity for internal resource reallocation enables larger, multi-unit, multi-market firms to manage regional economic variations effectively, thereby facilitating growth and consolidation across markets (Giroud et al. 2024).

## 2.2 Labor Substitution and Productivity Enhancement

In addition to its effect on transaction cost, investment in IT often directly enters a firm's production and therefore has a direct impact on its overall output and the use of labor. 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 lead 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, one overlooked dynamic factor in this line of argument is that firms that adopted advanced technology tend to have higher productivity, and thus increase overall revenue and aggregated employment (e.g., see Brynjolfsson and Mendelson 1993, Berndt and Morrison 1995, Acemoglu and Restrepo 2018 for examples).

Earlier studies point out a slowing down of productivity growth in the 1970s and 1980s despite the fast adoption of IT - "the IT productivity paradox" (Solow 1987). One of the main driven factors is the lack of accumulation of organizational innovation, complementary human capital, business process re-engineering, and other intangible assets (Brynjolfsson and Milgrom 2012). And the investment and accumulation of these intangible assets take time and therefore the productivity-enhancing effect of IT was not able to be captured by earlier empirical studies (Brynjolfsson et al. 2021a). Later studies find consistent results that IT has a positive and significant impact on firm profitability (e.g., Bharadwaj 2000) and productivity (e.g., Brynjolfsson and Hitt 2003, Tambe and Hitt 2012). Hence, the substitution of IT for labor does not necessarily result in smaller firm size, especially when given enough time for firms to accumulate complementary intangibles to fully realize the benefit of IT.

As firms accumulate intangible assets over time as IT further diffuses into our economy, increases in IT productivity could materialize and even become dominant in the long run. Combined

with the nature of high fixed cost and economy of scale of IT, larger adopters tend to benefit significantly more and grow faster than their smaller counterparts, and potentially lead to an increasing concentration (e.g., Tambe and Hitt 2012). For instance, French manufacturing firms that adopted robots tend to have higher productivity with an expansion of overall employment and market share (Acemoglu et al. 2020).

Furthermore, by allowing firms with heterogeneous productivity to compete monopolistically, Hsieh and Rossi-Hansberg (2019) propose that IT is one of the key driving forces for the increasing firm size. They 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. However, high-productivity firms benefit more, compared with low-productivity firms, from adopting the new technology. One particular argument within their model is that IT, as the general purpose technology (e.g., Rosenberg and Trajtenberg 2004), enables the geographic expansion of firms (particularly in retail, services, and wholesale sectors) by lowering the costs of codifying and transferring information, as well as monitoring. This is consistent with Zolas et al. (2020) who report that advanced technology adoption is heavily skewed towards larger and more productive firms. And consequently, IT appears to primarily enhance the productivity of larger firms, with a lag that can be attributed to the need for both tangible and intangible complementary assets accumulation (Bresnahan et al. 2002, Tambe et al. 2020).

As the result, firms with higher productivity will further increase their size in overall employment and revenue. These firms also tend to enter more markets and to be more profitable relative to average or low-productivity firms. Therefore, a menu of new technologies increases industry concentration in the long run. Several recent studies have documented an increase in market concentration across a wide range of sectors - especially in wholesale, retail, and service sectors in the U.S. economy, in which IT is mostly identified as a potential cause (e.g., Autor et al. 2020, Hsieh and Rossi-Hansberg 2019). Furthermore, Kwon et al. (2022) provides evidence that the rising concentration was primarily present in the manufacturing and mining sectors before 1970 but was then stronger in services, retail, and wholesale sectors afterward, in parallel with the timing

of IT adoption across sectors. In a recent paper, Bessen (2020) further analyzes industry-level concentration data from the U.S. Census and finds a strong link between IT and the rising industry concentration.

# 3 Stylized Facts in the US Economy

Based on the 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.[4]

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.[5] 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.[6] 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).[7] 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),

[4]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 detailed section definitions in Autor et al. (2020), Hsieh and Rossi-Hansberg (2019).

[5]Please see detailed discussion of this data below in section 5.

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

[7]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.

these trends for market concentrations are robust when other concentration ratio measures are used (i.e., CR20 and Herfindahl-Hirschman Index (HHI)).[8] 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. Further validation test indicates that the average change of the log employment share during this period based on our data is similar to those reported in Hsieh and Rossi-Hansberg (2019).[9]

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.[10] In section 7.6, 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

[8]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.

[9]Hsieh and Rossi-Hansberg (2019) 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).

[10]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.

with faster increases in average sizes and concentration rates are also the ones with faster growth in IT expenditures. This paper seeks to explain the macro-level trends by investigating the role of IT in the micro-level mechanism.

# 4 A Simple Model and Main Theoretical Results and Predictions

Inspired by the statistics presented in Section 3, we develop a simple model to derive empirical predictions over the implications of IT investment on firm size, firms' number of establishments, markups, and concentration.

## 4.1 The Model

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

Each firm $j$'s local branch in city $i$ and in period $t$ simultaneously chooses its individual output level $q_{ijt}$, where $j = 1, ..., n_{it}$. 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 $j$ in city $i$ 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 $j$ has active branches in period $t$ in $N_{jt}$ cities, then, it draws $N_{jt}$ marginal costs, one for each city it is active. Therefore, $\mathbf{c_{jt}} = \{c_{1jt}, c_{2jt}, ..., c_{N_{jt}jt}\}$ is the vector of marginal costs firm

$j$ 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.[11] 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, in overall, across all branches.

Formally, let $c_{jt}^{min} = \min\{c_{1jt}, c_{2jt}, ..., c_{N_{jt}jt}\}$. Let also $\varphi_{jt} \in [0,1]$ be the ability of firm $j$ in period $t$ to transfer knowledge from its most efficient branch with $c_{jt}^{min}$, say $k$, to its other branches. For each city $i \neq k$, the marginal cost can be reduced from the initially drawn value $c_{ijt}$ to value $\tilde{c}_{ijt}$, such that: $c_{ijt} - \tilde{c}_{ijt} = \varphi_{jt}(c_{ijt} - c_{jt}^{min})$. When $\varphi_{jt} = 0$, firm $j$ does not have any ability to replicate the business processes of its most efficient branch and therefore 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 $\varphi_{jt} = 1$, the firm can fully replicate and transfer the efficiency of its branch $k$ and therefore, the marginal cost in all cities it is active becomes $c_{jt}^{min}$. If instead, $i = k$, then, $\tilde{c}_{kjt} = c_{jt}^{min}, \forall \varphi_{jt} \in [0,1]$.

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

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. In other words, firms incur their IT costs in each city $i \neq k$ and period $t$ regardless of how much they produce, which is why IT investment represents a fixed cost (De Ridder 2024).

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

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

Note that firms invest in IT in each period $t$. This 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 $j$ in city $i$ 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 $j$ being active in $N_{jt} > 1$ cities, in period $t$, be denoted as $\Psi(N_{jt}) > 0$, with $\Psi(1) = 0$ and $\Psi(N_{jt} = N) \to +\infty$. Convexity dictates $\Psi(N_{jt} + 1) - \Psi(N_{jt}) > \Psi(N_{jt}) - \Psi(N_{jt} - 1)$. This assumption ensures some variation over the number of cities each firm is active. We can therefore investigate how a firm's IT investment is related with the firm having branches or establishments in more cities or local markets.

The inverse demand function in city $i$ and time period $t$ is $P_{it}(Q_{it}) = A_i - b_i Q_{it}$, where $Q_{it} = \sum_{j=1}^{n_{it}} q_{ijt}$ is the total market output and $A_i, b_i > 0$ are city-specific demand parameters. Hence, the profit function of firm $j$ from city $i$ in time period $t$ is

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

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

The profit of firm $j$ from being active in $N_{jt}$ cities in period $t$ is given by:

$$\Pi_{jt} = \pi_{kjt}(q_{kjt}, c_{jt}^{min}) + \sum_{i \neq k} \pi_{ijt}(q_{ijt}, c_{ijt}; \varphi_{jt}) - \Phi_{jt}(\varphi_{jt}; \xi_j) - \Psi(N_{jt}). \tag{3}$$

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

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

1. Each firm $j$ invests $\Phi_{jt}(\varphi_{jt}, \xi_j)$ in IT capital.

2. After each firm $j$ 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 in how many cities, $N_{jt}$ it will be active. It accordingly hires labor $l_{ijt}$.

## 4.2 Analysis

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

of each period $t$, after each firm $j$ observes the marginal costs of all firms in each city, it chooses (simultaneously with its competitors) its output level per city $q_{ijt}$ as well as in how many cities, $N_{jt}$ it will be active.[12] It accordingly employs labor $l_{ijt}$.

We assume that $A_i + (n-1)\underline{c} > n_{it}\overline{c}$ to ensure that the unconstrained Cournot equilibrlium 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 $j$ in city $i$ in time period $t$ is*

$$q^*_{ijt} = \frac{1}{b_i}\left(\frac{A_i + \sum_{y\neq j}\tilde{c}_{iyt} - n_{it}\tilde{c}_{ijt}}{n_{it}+1}\right). \tag{4}$$

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

$$\pi^*_{ijt} = (A_i - b_i Q^*_{it} - \tilde{c}_{ijt})q^*_{ijt}, \tag{5}$$

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

**Proof** *All proofs are derived in the appendix.*

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

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

- It reduces output produced by each of its competitors in city $i$ (strategic effect).

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

- It increases its own output (direct effect).

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

For the equilibrium profit $\pi^*_{ijt}$, we have $\frac{\partial \pi^*_{ijt}}{\partial \tilde{c}_{ijt}} = -\frac{n_{it}}{n_{it}+1} q^*_{ijt} - \frac{(P(Q^*_{it}) - \tilde{c}_{ijt}) n_{it}}{b_i(n_{it}+1)} < 0$, so, profit $\pi^*_{ijt}$ is higher in all cities other than $k$ when firm $j$ invests more on IT capital. Moreover, $\frac{\partial^2 \pi^*_{ijt}}{\partial \tilde{c}^2_{ijt}} = \frac{2n^2_{it}}{b_i(n_{it}+1)^2} > 0$. The marginal positive impact of firm $j$'s IT investment on its profit becomes smaller as we move to higher levels of production efficiency suggesting a concave relationship between firm $j$'s profit and IT investment.

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

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

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

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

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

When firm $j$ is active in $N_{jt}$ cities, it will only choose to be active in an additional city $i$ if $\pi^*_{ijt} > \Psi(N_{jt}+1) - \Psi(N_{jt})$. When firm $j$ 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 help firms to enter to more local markets and have establishments in more distinct locations (cities).*

The Cournot equilibrium output in each city $i$ has also implications for firm $j$'s employment in each period $t$. Following (1), firm $j$ employs $l^*_{ijt} = \frac{q^*_{ijt}\tilde{c}_{ijt}}{w}$ workers in city $i$. IT investment affects equilibrium employment in each city $i \neq k$ 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 $j$, in city $i \neq k$ and in period $t$, $l^*_{ijt}$ and firm $j$'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 $j$'s IT investment and therefore the output expansion channel dominates when firm $j$'s production efficiency is relatively low with respect to the average production efficiency of its competitors in city $i$,*

$$A_i + \sum_{y \neq j} \tilde{c}_{iyt} < 2n_{it}\tilde{c}_{ijt}. \tag{6}$$

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

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

- City expansion channel: As IT investment increases, firm $j$ 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 $j$, $\pi^*_{ijt}$ 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 $j$, in city $i$ and in period $t$. Then,

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

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

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

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

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

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

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 $j$ in period $t$ is derived by the following first order condition:*

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

Firms with higher IT investment efficiency (lower $\xi_j$) 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 $i \neq k$, 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.

## 4.3 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. If this output expansion is significant, then IT also leads to increases in firms' employment. This positive relationship between IT investment and firm-level employment is more pronounced for firms with lower levels of IT and size.*

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 to 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 sizes 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.*

# 5 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 unique 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).[13] The U.S. Census Bureau collects

[13] 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.

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 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.[14] 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, 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.[15] Given the objective and its prominence, the coverage and quality ensured by the U.S. Census

[14] 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.

[15] For more details of LBD, please see the Census website at: https://www.census.gov/programs-surveys/

Bureau is hard to match using external resources.

With access to these data, we can report not only the stylized facts above but also build a 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).[16]

For this firm-level data, both mean and standard deviation are reported for all key variables in Table 1. The sample means for the total number of employees exceeded 3,800 and the average annual sales were over one billion U.S. dollars. 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.[17] Moreover, we conduct additional analysis using

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.

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

[17] 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.

weighted regression using the ACES and ICTS sample weights to further test the robustness of our findings against the sample selection issue.

# 6 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 its core industry, and, thereafter, directly link these to industrial concentration because our data covers the universe of the 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).[18] 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.[19] Here, the main coefficients of interest are $\beta_1$, 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

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

[19] 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.

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

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

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 $\beta_1$ together captures the heterogeneous effect of IT across size groups.

## 6.1 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 technology 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.[20] Bessen (2020) calculates the distribution of sedentary occupations for industries using the 2000 census public-Use micro-data, four years before our data begins. In conjunction with the fact that a firm's sedentary workforce is likely being 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 include 264 industries that are mostly at four and five digits of NAICS codes. On average, the proportion of sedentary workers is about 43.5%.

# 7 Results

## 7.1 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 firm's future employment and market share of employment. Given the definition of IT intensity (i.e., using total employment as 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. Columns 1 and 2 present the results for employment while columns 3 and 4 present the results for employment share in its core industry. In column 1, The coefficient on $log(ITintensity)$ shows that a one percent increase in IT intensity is associated with a 0.056 percent increase in firm employment in the following year. The result is similar when we control for IT and non-IT intensities in the previous year, as presented in column 2. Similarly, column 3 shows that the

[20]This data and its description can be accessed via this link: https://www.icpsr.umich.edu/web/ICPSR/studies/8942.

following year, a one percent increase in IT intensity is associated with a 0.015 percent change in the firm's share of total industrial employment size. 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 sales and market share of sales and present the results in Panel B of Table 2.[21] Controlling for employment, columns 1 and 2 in Panel B show that a one percent increase in the firm's IT intensity measure is associated with approximately 0.1 percent increase in sales. Columns 3 and 4 show the regression results when a firm's sales share is the dependent variable. They show that higher IT intensity is also associated with higher sales and large market 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.[22] 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 employment while Panel B presents the results for firm sales. In both panels, the results are similar to those reported in our baseline models. The coefficients of IT are consistently large, positive,

[21] We use contemporaneous sales and market share of sales in this set of analysis as the calculation of IT intensity measure has not involved them directly.

[22] 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.

and highly significant, suggesting that higher IT capital investment is positively associated with an increase in firm size with respect to employment, sales, and the corresponding market shares in their core industries.

As evidenced by comparing the coefficients in columns 1 and 2 in Panel B and Panel A 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 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 4.3. It is also consistent with the findings of (n.d.), Tambe and Hitt (2012), Acemoglu and Restrepo (2020), and in line with "scale with mass" theory and the declining trend of labor share, which we predicts in Empirical Prediction 1 above and explore further in the latter sections.

## 7.2 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 7.2.1 and 7.2.2, respectively.

### 7.2.1 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 employment from one-year-difference to five-year-difference specifications, respectively.[23] Similar to previous sections, the left-hand side variable is also the firm's log employment in year $t + 1$. In all specifications, we control for firm, year, and industry fixed effects. 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 A. 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.

On the other hand, Panel B of Table 4 reports the results of difference models using sales as our outcome variable. The results are largely consistent with our findings above, with respect to sales. 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, especially during the first three years. However, the effect of IT intensity on sales seems to fade away over the long run as the coefficients decrease and are less statistically significant. Nevertheless, by comparing the results for employment in Panel A where the effect of IT intensity seems to be short-lived, the effect on firms' sales seems to be more pronounced and more persistent.

These results provide some supporting evidence for the causal relationship between the increasing IT intensity and firm size as measured by employment and sales, consistent with those

[23] 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.

presented in Tables 2 and 3.

### 7.2.2 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 present the results for employment in year $t+1$. 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. Unlike the results presented in earlier Tables 2, 3, and 4, columns 1 and 2 here show no statistically significant coefficients on IT intensity. This reveals a surprising non-effect of IT intensity on firm size with respect to employment in the IV estimation and weakens the causal argument for Hypothesis 1 that IT increases firms' employment.

Columns 3 and 4 in Table 5 examine the impact of IT on sales following the same IV strategy. In contrast to the results for employment, both columns 3 and 4 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. The comparison between these results and the ones for employment (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).

## 7.3 IT intensity and Labor Share

Previous sections provide evidence that IT intensity could lead to faster growth in firms' sales but without expanding its employment to a similar scale, suggesting a declining labor share of firms' output as described in Empirical Prediction 2 in Section 4.3. 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 7.2.1 and 7.2.2 to address the potential endogeneity issue, we also adopt long-difference models and IV strategy and present the results in Panel B of and Columns 5 to 6 of Panel A in Table 6, respectively. The results are largely consistent with the baseline result, indicating that the negative correlation between IT intensity and firms' labor share is likely causal.

## 7.4 Mechanism Tests

As predicted by our model described in Section 4, 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.

## 7.5 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 4 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 employment, sales, 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.[24] The result in Panel (a) 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 the extent by a relatively smaller scale in terms of the percentage change. However, because the average firm size increases fast from the first to the fifty quintiles, the effect magnitude in terms of level actually increases monotonically.

Similarly, the result in Panel (b) shows that a higher IT intensity is also associated with greater sales but this effect increases monotonically with firm sizes and is only significantly different from

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

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 7.6. In addition, the larger effects of IT on sales (compared to employment) are more pronounced among the firms in larger size quintiles.

As we have already shown in earlier tables, the estimated effect of IT on sales is much larger than its effect on employment, especially in the IV estimation (see columns 1 and 2 in both panels of Table 5) and thus would on average lead to a decline in labor share (i.e., Table 6). In panel (c), 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).

## 7.6 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 long-difference model (Brynjolfsson and Hitt 2003, Bessen 2020).[25] 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. $\Delta IT_j$ indicates the differences in average IT hardware and

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

software capital expenditure between 2004 and 2013 in a given industry. The coefficient of interest in equation 9 is $\beta_{IT}$, 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 employment in the top 10% firms–while columns 4 to 6 present results from similar models for sales. The left-hand side variables are the change in log industrial concentration measures 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 employment 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 employment 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 sales 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.

# 8 Summary and Conclusion

Economic activities, either within firms or in markets, are accompanied by information processing. Over the past several decades, as digital technology has advanced, the cost of information processing has declined significantly. As a result, it would be surprising if IT did *not* affect the boundaries of firms and markets.

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 cost and/or enhancing productivity with market expansion have been the dominant effects of IT in recent years.

In this paper, we first document a set of stylized facts that are in agreements with these predictions. First, we show both the average firm size and industrial concentration rates are increasing for a number of major sectors in the last two decades. The rising industrial concentration appears in both employment and sales but has been most pronounced in sales. Meanwhile, the sectors with higher growth of the average firm size and industrial concentration also show a more rapid increase in IT investment.

We then develop a Cournot competition model that studies how firms' IT investments affect their output production, market shares and market concentration. We derive three mechanisms that contribute to the relationship between IT investment and firms' size deriving four empirical predictions on the impact of IT. Our model points towards heterogeneous effects of IT investment on firms' size and market shares.

Our study proceeds by providing empirical evidence that the adoption of IT is associated with the increasing firm size in the last decades. Taking advantage of US Census firm-level data, we provide evidence that a higher IT intensity is associated with larger firm size, growth in sales, as well as increases in the corresponding market shares of the largest firms. Our findings are robust to alternative specifications such as adding lagged IT measures, additional controls, and weighted

regressions. Our results are also robust when using alternative IT measures.

Long-difference models spanning up to five years provide additional evidence that the relationship between IT and firm size is likely to be causal. Results using the share of sedentary workers at the industry level as an instrument for IT adoption provide further evidence suggesting that the identified positive effect of IT on firm size, especially sales, is causal.

Furthermore, the effect of IT on sales is significantly larger than its effect on firm employment, consistent with the "scale without mass" prediction. In addition, we investigate the underlining mechanisms through which the higher IT intensity leads to larger firm size. Taking advantage of the detailed firm-level data, we first provide evidence that investment in IT enables business replication and allow firms to enter more local markets and industries. These results are also robust with the IV strategy.

We further show that the relationship between IT and firm size is particularly pronounced in larger firms. The enabling effect of IT and the heterogeneity effect of IT across firm size groups thus speak to the debate that IT has an important impact on market structure and contributes to the rise of industrial concentration and the growth of superstar firms. Our findings remain robust when various measures of firm size and industrial concentration (both level and shares of employment and sales) are employed, and when various IT measures are used. long-difference models at the industry level also confirm that industries with a larger IT investment experienced a faster increase in industrial concentration, a result that is consistent with the prior study (Bessen 2020).

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# Figures and Tables

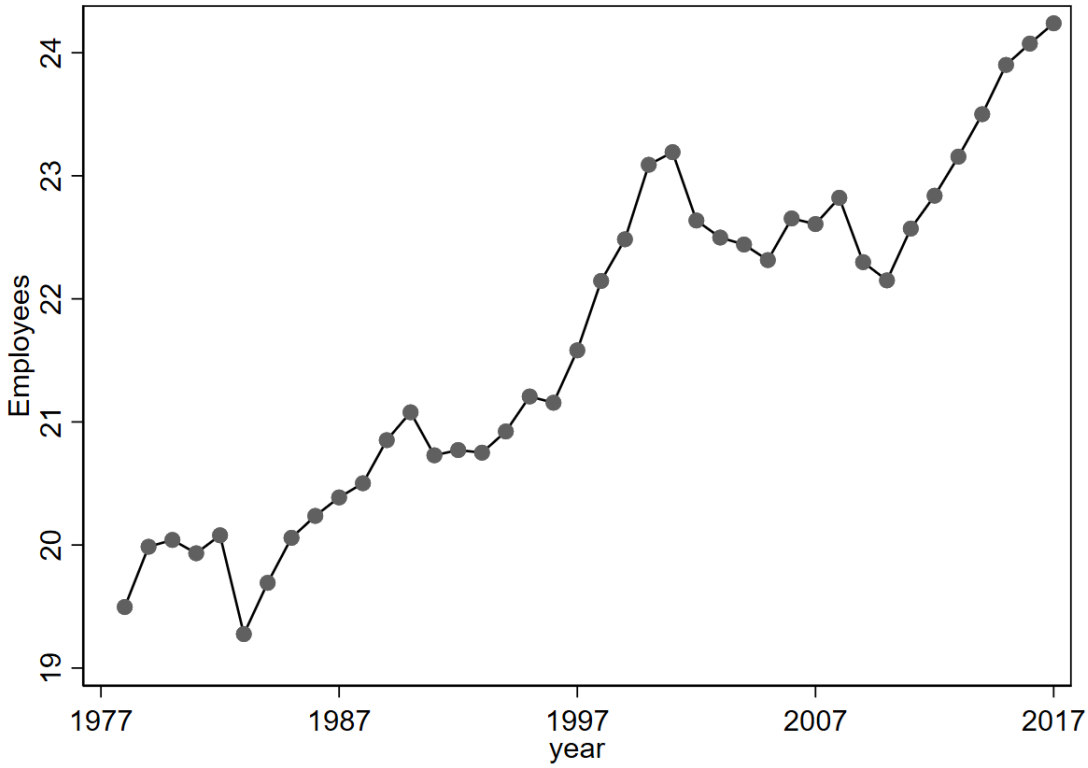



Figure 1: Average Firm Employment Size in the US (1978-2017)

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

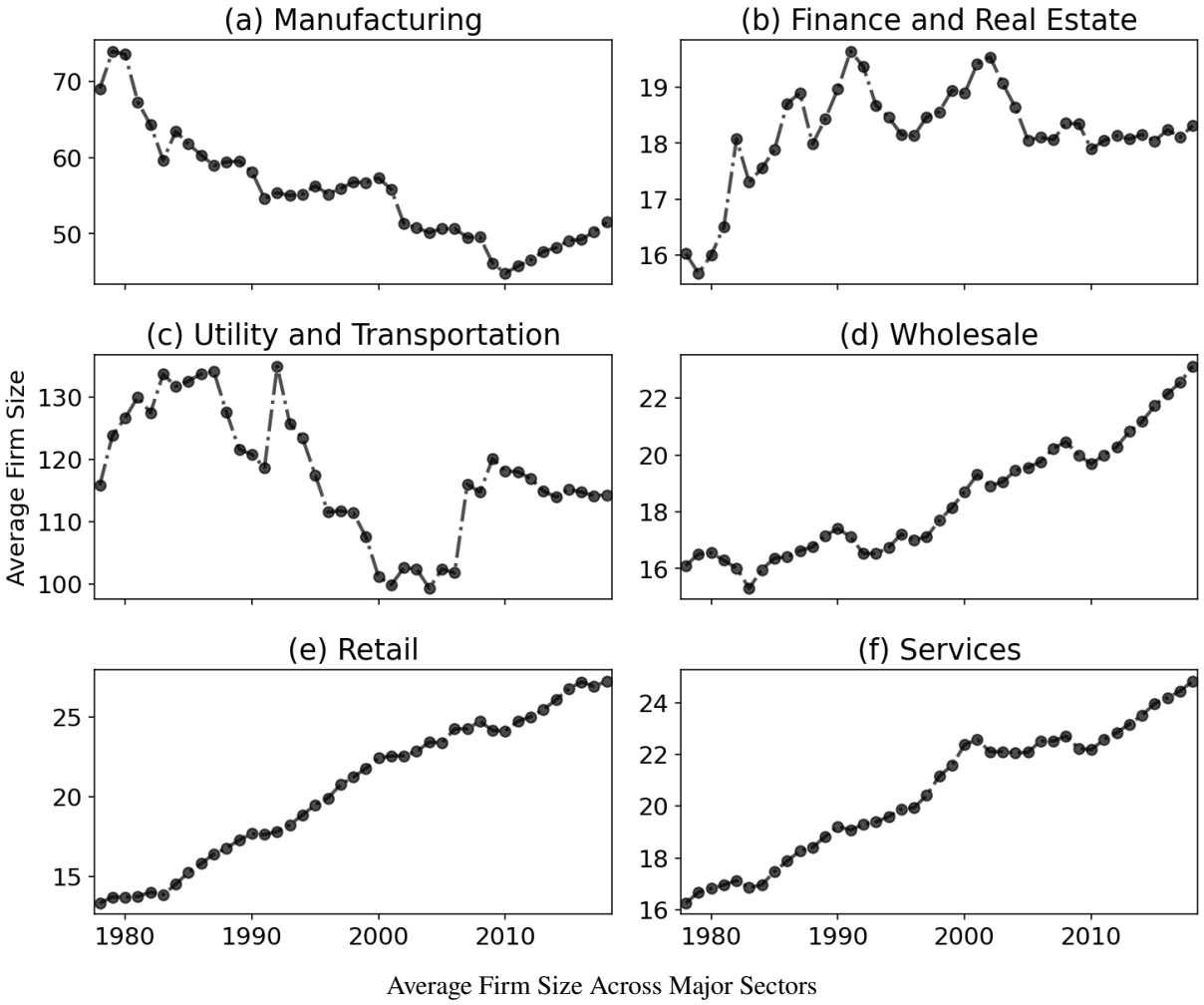



Figure 2: Average Firm Employment Size in the US (1978-2017)

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

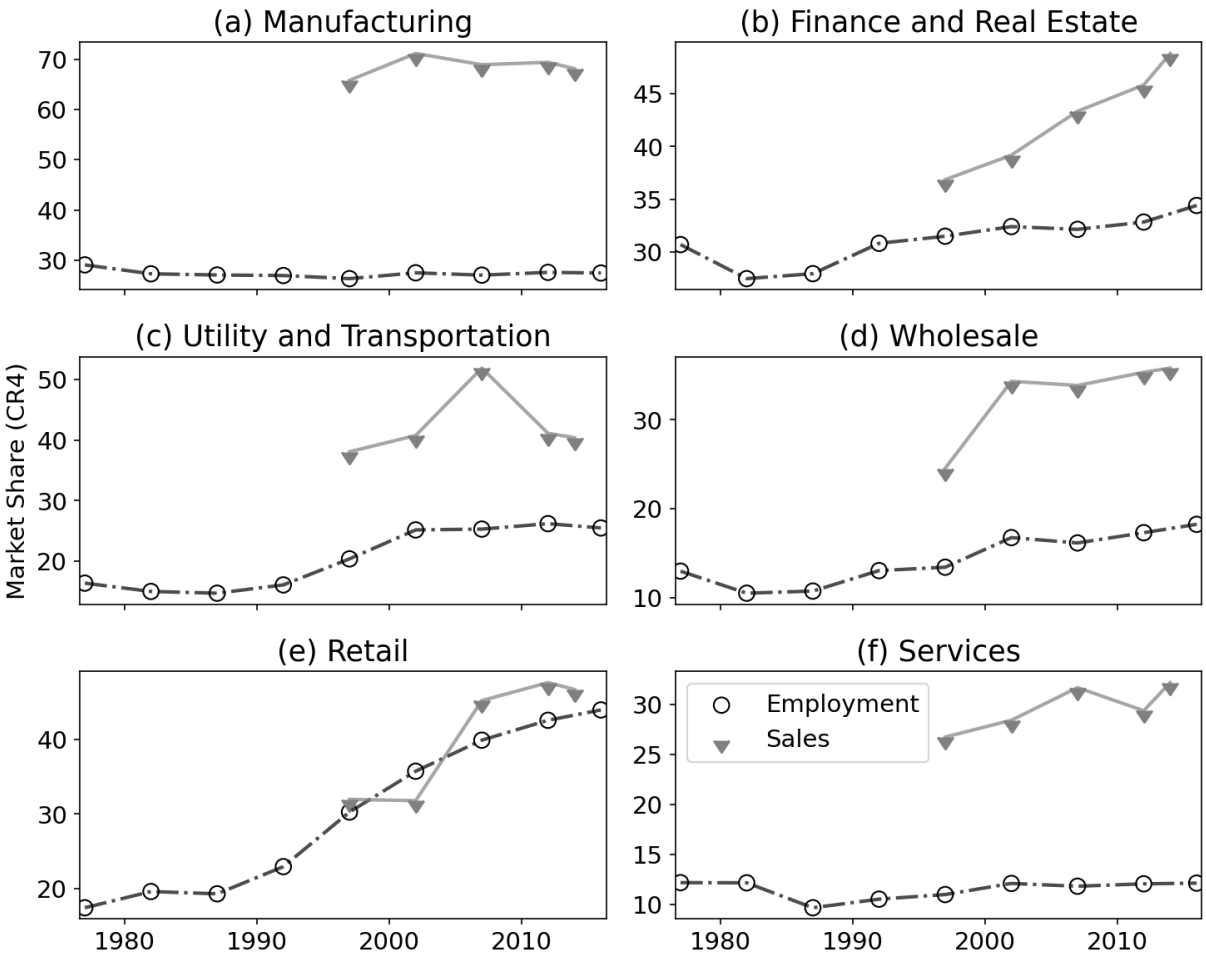



Figure 3: Employment and Sales Concentration Rates for Top 4 Firms

Note: This figure presents the weighted average concentration Rate 4 (CR4) at six digital NAICS levels in six major sectors. The reported statistics are based on the authors' calculations using the Revenue-enhanced version Longitudinal Business Database (LBDRev). The industry level 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.

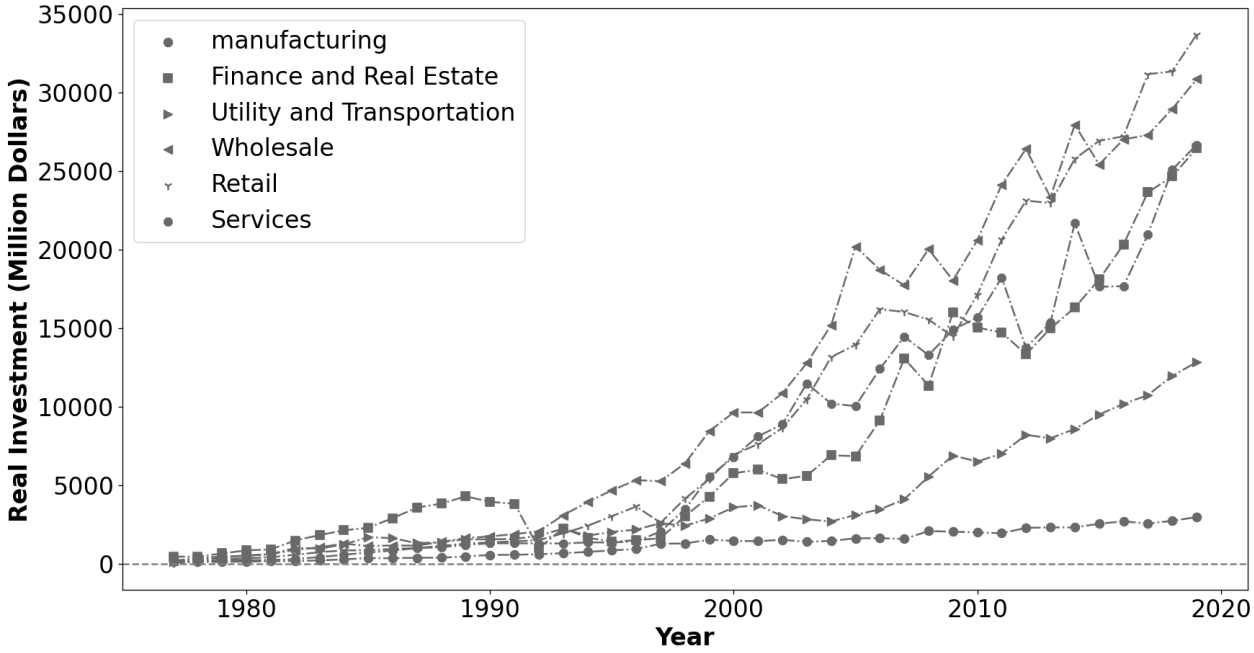
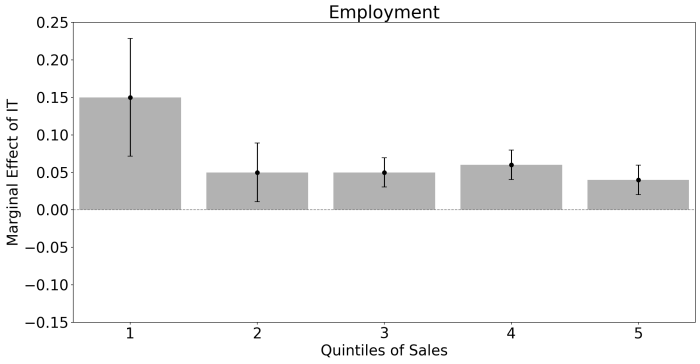
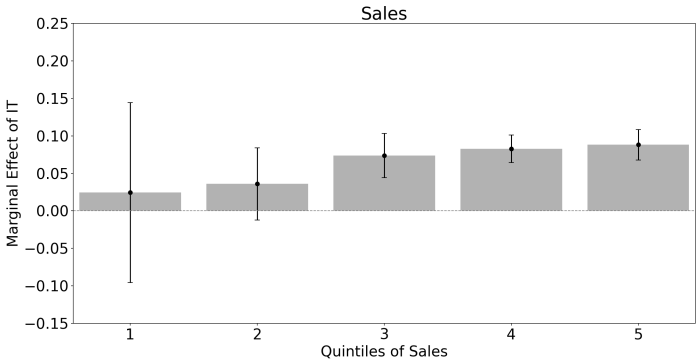



Figure 4: IT Capital Investment by Sectors

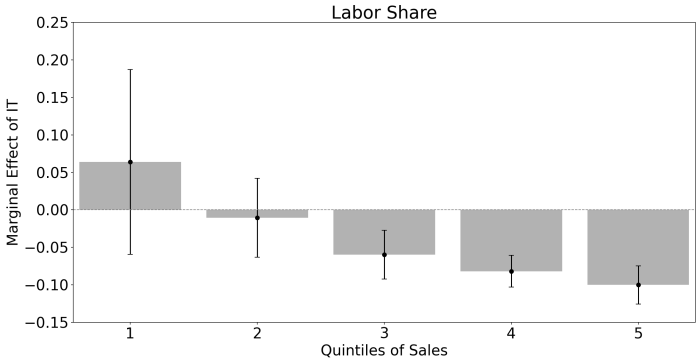
Note: This figure presents the total real IT investment in six major sectors. The reported statistics are based on the authors' calculation using investment series for private nonresidential fixed assets on all IT-related categories from the Bureau of Economic Analysis (BEA). The total IT capital investment is the sum of 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.




(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 employment (Panel a), sales (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 |
|---|---|---|---|
| Total Employment | 3,850 | 20,890 | ~50,000 |
| Sales (M) | 1,121 | 6,260 | ~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 employment share is calculated as the share of the firm's employment in the total employment of the six-digit NAICS industry. Firm's sales share is calculated as the share of firm's sales in the total sales 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: 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 |

Panel B: 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 |

Note: 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. Firm's employment share is calculated as the share of the firm's employment in the total employment of the six-digit NAICS industry. Firm's sales share is calculated as the share of firm's sales in the total sales of the six-digit NAICS industry. 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: 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 |

Panel B: 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 |

Note: 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. Firm's employment share is calculated as the share of the firm's employment in the total employment of the six-digit NAICS industry. Firm's sales share is calculated as the share of firm's sales in the total sales of the six-digit NAICS industry. 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: 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 |

Panel B: 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 |

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. | Employment (t+1) | | Sales | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| log(IT Intensity) | 0.002 | 0.007 | 0.645*** | 0.660*** |
| | (0.006) | (0.027) | (0.043) | (0.135) |
| log(Non-IT Intensity) | 0.017*** | 0.028*** | 0.325*** | 0.168*** |
| | (0.002) | (0.007) | (0.016) | (0.037) |
| Log(Emp) | 0.984*** | 0.978*** | 0.938*** | 0.927*** |
| | (0.001) | (0.002) | (0.008) | (0.009) |
| 1st Stage coefficient | 0.928*** | 0.606*** | 0.935*** | 0.593*** |
| | (0.025) | (0.051) | (0.025 ) | (0.051) |
| KP Chi-sq | 968.1 | 140.9 | 966.6 | 132 |
| CD Wald F | 5800 | 384.3 | 5690 | 355.7 |
| KP Wald F | 1409 | 142.6 | 1408 | 133.2 |
| Year FE | Y | Y | Y | Y |
| Industry FE | | Y | | Y |
| R-squared | 0.954 | 0.945 | 0.674 | 0.692 |
| 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<br>Δ log(emp HHI) | 2<br>Δ log(emp CR4) | 3<br>Δ log(emp top 10%) | 4<br>Δ log(sale HHI) | 5<br>Δ log(sale CR4) | 6<br>Δ log(sale top 10%) |
|---|---|---|---|---|---|---|
| Δ log(IT) | 0.084*** | 0.012*** | 0.047*** | 0.080*** | 0.010*** | 0.037*** |
| | (0.014) | (0.002) | (0.008) | (0.022) | (0.003) | (0.011) |
| R-squared | 0.042 | 0.042 | 0.043 | 0.015 | 0.015 | 0.014 |
| 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 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:

$$-b_i q_{ijt} + A_i - b_i Q_{it} - \tilde{c}_{ijt} = 0.$$

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

$$2b_i q_{ijt} + b_i \sum_{l \neq j} q_{ilt} = A_i - \tilde{c}_{ijt}.$$

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

$$\mathbf{q}_{it} = \begin{pmatrix} q_{i1t} \\ q_{i2t} \\ . \\ . \\ . \\ q_{in_{it}t} \end{pmatrix}, \quad \mathbf{M}_{it} = b_i \begin{pmatrix} 2 & 1 & . & . & . & 1 \\ & & . & & & . \\ 1 & 2 & & . & & . \\ & & & & . & . \\ . & . & & . & & \\ . & & . & & & 1 \\ . & & & . & & \\ 1 & . & . & . & 1 & 2 \end{pmatrix}, \quad \mathbf{R}_{it} = \begin{pmatrix} A_i - \tilde{c}_{i1t} \\ A_i - \tilde{c}_{i2t} \\ . \\ . \\ . \\ A_i - \tilde{c}_{in_{it}t} \end{pmatrix},$$

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

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

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

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

where,

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

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

## A.2 Proof of Corollary 1

It immediately follows from the marginal effects of $\tilde{c}_{ijt}$ on $q^*_{ijt}$ and $Q_{it}$. From Cournot equilibrium (4), we have: $\frac{\partial q^*_{ijt}}{\partial \tilde{c}_{ijt}} = -\frac{n_{it}}{b_i(n_{it}+1)} < 0$ and $\frac{\partial Q^*_{it}}{\partial \tilde{c}_{ijt}} = \frac{n_{it}-1}{b_i(n_{it}+1)} - \frac{n_{it}}{b_i(n_{it}+1)} = \frac{-1}{b_i(n_{it}+1)} < 0$.

In the latter expression, the term $\frac{n_{it}-1}{b_i(n_{it}+1)}$ refers the strategic effect of firm $j$'s IT investment on aggregate output and the term $\frac{n_{it}}{b_i(n_{it}+1)}$ refers to the direct effect of firm $j$'s IT investment aggregate output. These two effects are opposite in sign. As firm $j$ invests more on IT capital, its competitors in city $i$ produce less output and firm $j$ 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 $j$ implies that firm $j$ has a lower marginal cost in comparison to the average marginal cost of its competitors. Following expression (4), this means that firm $j$ has in equilibrium a higher output level.

## A.3 Proof of Proposition 2 and Corollary 2

As firm $j$ is active in more cities, the second and fourth term in total profit (3) admit higher values. Since these two firms have opposite sign, 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 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 $\pi_{ljt}$ is greater than the additional overhead cost from operating in one more city. Firm $j$ when it finds profitable to operate in $N_{jt}$ cities will find profitable to operate in one more city $l$, so in $N_{jt}+1$ cities in total only if:

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

The optimal number of cities firm $j$ is active is the lowest number of cities $N^*_{jt}$ for which this condition does not hold. It should also be $\Pi^*_{jt}(N_{jt}) - \Pi^*_{jt}(N_{jt}-1) > 0$ which ensures that $N^*_{jt}$ is

the maximum number of cities at which firm $j$ finds it profitable to operate.

As $\pi^*_{ljt}$ is strictly increasing in firm $j$'s IT investment, from the above conditions, the optimal number of cities $N^*_{jt}$ is also increasing with IT investment.

## A.4 Proof of Lemma 1

It is

$$l^*_{ijt} = \frac{\tilde{c}_{ijt}}{b_i w} \frac{A_i + \sum_{y \neq j} \tilde{c}_{iyt} - n_{it}\tilde{c}_{ijt}}{n_{it}+1}.$$

So,

$$\frac{\partial l^*_{ijt}}{\partial \tilde{c}_{ijt}} = \frac{A_i + \sum_{y \neq j} \tilde{c}_{iyt} - n_{it}\tilde{c}_{ijt}}{b_i w(n_{it}+1)} - \frac{n_{it}\tilde{c}_{ijt}}{b_i w(n_{it}+1)} = \frac{A_i + \sum_{y \neq j} \tilde{c}_{iyt} - 2n_{it}\tilde{c}_{ijt}}{b_i w(n_{it}+1)}.$$

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.5 Proof of Corollary 3

Following the definition of $l^*_{ijt}$, the labor share of production of firm $j$ in city $i$ 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 $\lambda^*_{ijt}$ is strictly declining in firm $j$'s IT investment.

## A.6 Proof of Corollary 4

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

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

Moreover,

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

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

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

$$\frac{\partial q^*_{imt}}{\partial \tilde{c}_{ijt}} = \frac{1}{b_i(n_{it}+1)} > 0.$$

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

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

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

So, firm $j$'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 $j$'s IT investment on $HHI_{it}^{*}$ 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:

$$\frac{\partial^2 a_{imt}^{*}}{\partial(\tilde{c}_{ijt})^2} = \frac{Q_{it}^{*} + q_{imt}^{*}}{b_i^2(n_{it}+1)^2 Q_{it}^{*}} > 0.$$

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

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

$$\frac{\partial HHI_{it}^{*}}{\partial \tilde{c}_{ijt}} = \frac{\partial}{\partial \tilde{c}_{ijt}}\left(\sum_{m\neq j}\left(\frac{q_{imt}^{*}}{Q_{it}^{*}}\right)^2\right) + \frac{\partial}{\partial \tilde{c}_{ijt}}\left(\frac{q_{ijt}^{*}}{Q_{it}^{*}}\right)^2.$$

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

$$\frac{\partial}{\partial \tilde{c}_{ijt}}\left(\sum_{m\neq j}\left(\frac{q_{imt}^{*}}{Q_{it}^{*}}\right)^2\right) = \sum_{m\neq j}\frac{\partial}{\partial \tilde{c}_{ijt}}\left(\frac{q_{imt}^{*}}{Q_{it}^{*}}\right)^2 = \frac{2\sum_{m\neq j} q_{imt}^{*}}{b_i(n_{it}+1)(Q_{it}^{*})^2} + \frac{2\sum_{m\neq j}(q_{imt}^{*})^2}{b_i(n_{it}+1)(Q_{it}^{*})^3} > 0.$$

The other term refers to the direct effect which is:

$$\frac{\partial}{\partial \tilde{c}_{ijt}}\left(\frac{q_{ijt}^{*}}{Q_{it}^{*}}\right)^2 = 2\frac{-n_{it}Q_{it}^{*} + q_{ijt}^{*}}{b_i(n_{it}+1)(Q_{it}^{*})^2}\frac{q_{ijt}^{*}}{Q_{it}^{*}} < 0.$$

So, firm $j$'s IT investment can increase market concentration ($\frac{\partial HHI_{it}^{*}}{\partial \tilde{c}_{ijt}} < 0$) when the direct

effect dominates or it can decrease market concentration ($\frac{\partial HHI^*_{it}}{\partial \tilde{c}_{ijt}} > 0$) when the strategic effect dominates.

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

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

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

## A.7 Proof of Proposition 3

It immediately follows from the first-order condition over total profit (3) with respect to IT investment $\varphi_{jt}$.

## A.8 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.[26] 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

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

concentration.[27]

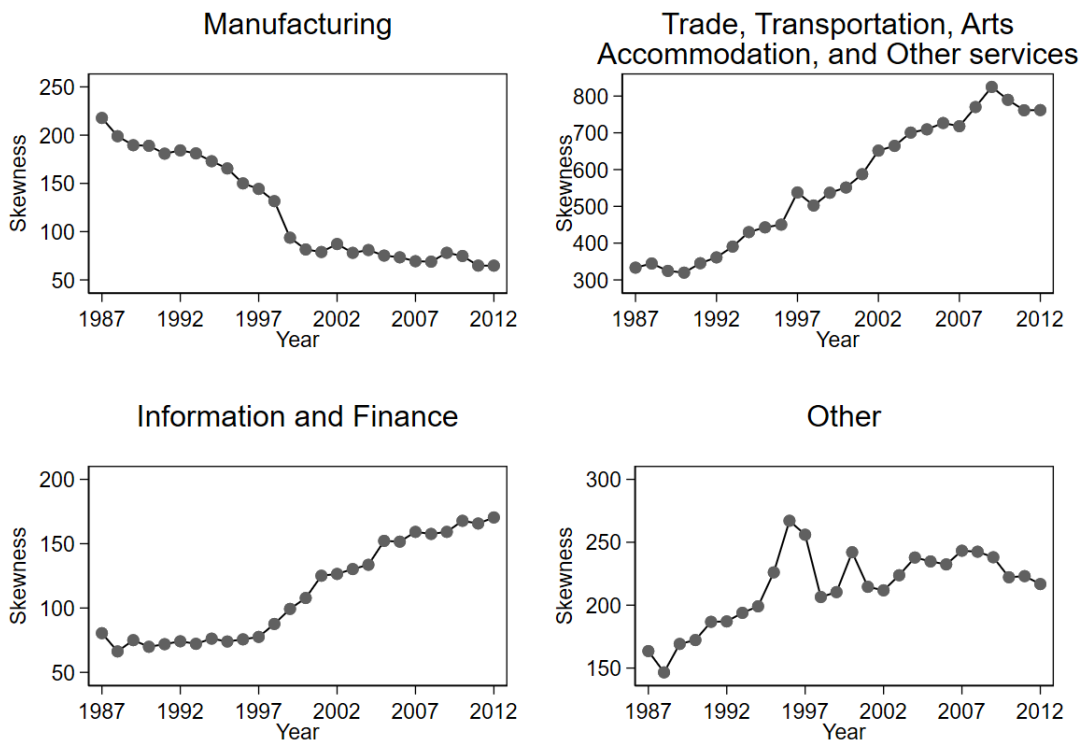



Figure A1: Skewness of Firm Employment Distribution by Major Sectors (1987-2012)

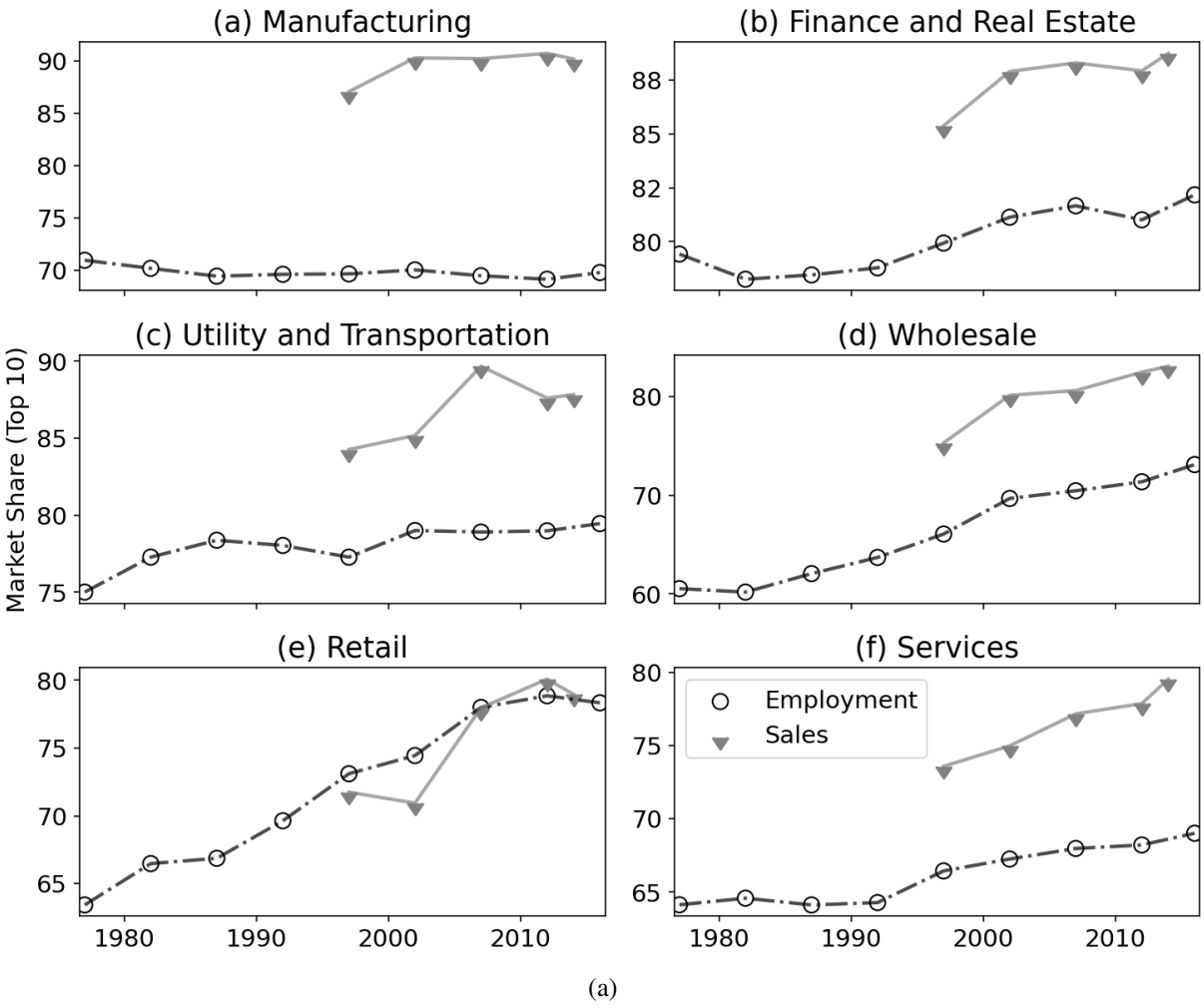
Note: Based on the Longitudinal Business Database (LBD). From Benzell & Brynjolfsson (2021). Manufacturing: NAICS 31-33; Trade, Transportation, Arts, Accommodation, and Other Services: NAICS 42, 44-45, 71, 72, 81; Information and Finance: NAICS 51, 52.

## A.9 Share of Top Ten Percent Firms

Following Hsieh and Rossi-Hansberg (2019), we present the evolution of the share of 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 top 10% firms. And it is true for

[27]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.

both employment and sales. To compare with Hsieh and Rossi-Hansberg (2019), we calculate the average change of log employment share during this period and find similar results. [28]




(a)

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

Note: we follow a method similar to Hsieh and Rossi-Hansberg (2019) 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.

[28] In Hsieh and Rossi-Hansberg (2019), 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.10 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.11 Alternative Instrumental Variable Specification

In addition to the instrumental variable (IV) strategy using the industry-level share of sedentary workers, we follow Barth et al. (2022) 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 show no statistically significant correlation between IT and employment but do so with sales. Similar to Columns 3 and 4, 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 7.

## A.12 Robustness Check with IT Expenditure

In addition to the results in Section 7, 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' employment, sales, and their corresponding industrial shares, but negatively associated with firms' labor share. These results are broadly consistent with our main findings reported above.

Table A1: Instrumental Variable Models
Two Year Lagged IT Intensity

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

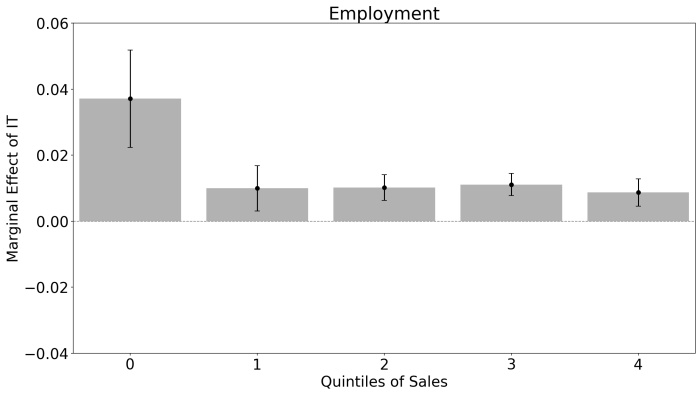
Table A2: IT Expenditure, Firm Size, Market Share, and Labor Share

| Dep.Var. | Employment (t+1) | | Employment Share (t+1) | | Sales | | Sales Share | | Labor Share | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| log(IT Expnd) | 0.0117*** | 0.0099*** | 0.0032*** | 0.0023* | 0.0167*** | 0.0149*** | 0.0033*** | 0.0028*** | -0.0102*** | -0.0088*** |
| | (0.0013) | (0.0015) | (0.0009) | (0.0012) | (0.0021) | (0.0020) | (0.0008) | (0.0008) | (0.0021) | (0.0020) |
| log(Other Expnd) | | 0.0069*** | | 0.0023** | | 0.0104*** | | 0.0019** | | -0.0072*** |
| | | (0.0015) | | (0.0011) | | (0.0023) | | (0.0008) | | (0.0023) |
| log(IT Expnd)(t-1) | 0.0121*** | 0.0114*** | 0.0032*** | 0.0023* | 0.0199*** | 0.0191*** | 0.0048*** | 0.0046*** | -0.0125*** | -0.0120*** |
| | (0.0015) | (0.0016) | (0.0011) | (0.0012) | (0.0020) | (0.0020) | (0.0008) | (0.0008) | (0.0020) | (0.0020) |
| log(Other Expnd)(t-1) | | 0.0045*** | | 0 | | 0.0123*** | | 0.0042*** | | -0.0094*** |
| | | (0.0015) | | (0.0010) | | (0.0020) | | (0.0008) | | (0.0020) |
| Log(Emp) | 0.3804*** | 0.3244*** | 0.1062*** | 0.0889*** | 0.3070*** | 0.2990*** | 0.0741*** | 0.0719*** | 0.4795*** | 0.4854*** |
| | (0.0196) | (0.0256) | (0.0113) | (0.0155) | (0.0199) | (0.0197) | (0.0063) | (0.0062) | (0.0229) | (0.0229) |
| Firm FE | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| R-squared | 0.9663 | 0.9688 | 0.9394 | 0.9446 | 0.9643 | 0.9644 | 0.9722 | 0.9722 | 0.8808 | 0.881 |
| Observations | ~50,000 | ~35,000 | ~50,000 | ~35,000 | ~50,000 | ~50,000 | ~50,000 | ~50,000 | ~50,000 | ~50,000 |

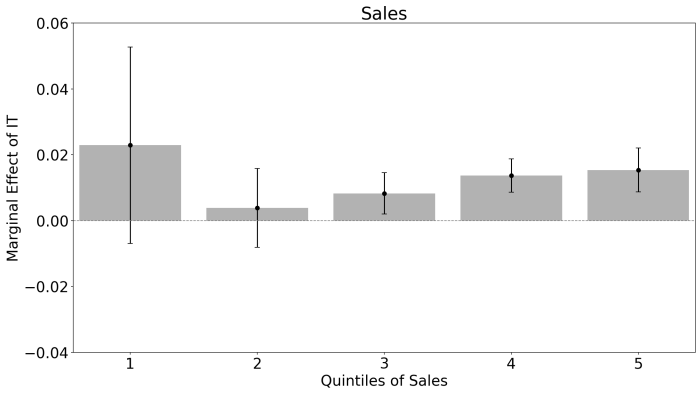
Note: The independent variables are the logarithm of the IT expenditures and non-IT expenditures. Firm's employment share is calculated as the share of the firm's employment in the total employment of the six-digit NAICS industry. Firm's sales share is calculated as the share of firm's sales in the total sales 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.

**Heterogeneous Effects of IT Expenditure on Firm Size by Size Category**

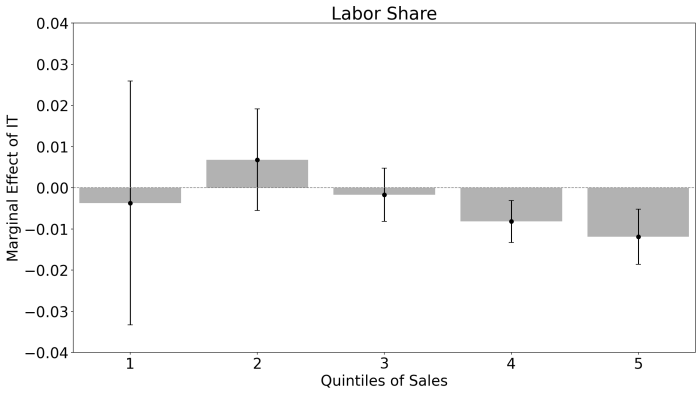
Similar to Figure 5, we follow equation 8 in section 6 and explore the effect heterogeneity of IT expenditure (instead of IT intensity) for different sized firms for an additional robustness check. The marginal effects of IT expenditure on employment, sales, and labor share are plotted in Figure A3 Panel (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 employment and sales, 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 employment (Panel a), sales (Panel b), and labor share (Panel c). Quintiles are based on sales distribution. Vertical lines represent the 95% confidence intervals.