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Chapter Author(s): Chris Forman, Avi Goldfarb

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Concentration and Agglomeration of IT Innovation and Entrepreneurship
Evidence from Patenting

Chris Forman and Avi Goldfarb

"We wanted flying cars, instead we got 140 characters."
—Peter Thiel

2.1 Introduction

This volume is partly motivated by Peter Thiel's criticism of recent innovation. Thiel's business success came in the field of information technology. The product he criticized as not sufficiently exciting—Twitter's 140 characters—is information technology. The product he emphasizes as something to aspire to—flying cars—will depend on information technology if it is to appear.

Information technology (IT) is at the center of much innovation over the past 50 years. As Brynjolfsson and McAfee (2014) have emphasized, IT matters to prosperity. Many of the most prominent companies and emerging industries either produce IT, use IT as a critical input, and/or produce digital goods and services. For example, of the top 10 companies in market capitalization in May 2019, seven are primarily IT companies (Statista 2019). The most valued startups (for example, as measured by billion-dollar valuations) are overwhelmingly IT (Evans and Gawer 2016). Recently there have been significant technological advances in IT, most prominently related to artificial intelligence and cloud computing.

Chris Forman is the Peter and Stephanie Nolan Professor of Strategy, Innovation, and Technology at the Charles H. Dyson School of Applied Economics and Management, Cornell University.

Avi Goldfarb is the Rotman Chair in Artificial Intelligence and Healthcare and Professor of Marketing at the Rotman School of Management, University of Toronto, and a research associate of the National Bureau of Economic Research.

IT is central to innovation, and this centrality has been increasing over time. Much of this innovation is focused on software (Arora, Branstetter, and Drev 2013). Manufacturing firms that are more software-intensive have been shown to have more patents per dollar spent on research and development (R&D), and their investments in R&D are more highly valued in equity markets (Branstetter, Drev, and Kwon 2019). More recently, Cockburn, Henderson, and Stern (2019) argue that advances in machine learning are primarily valuable because they make innovation more efficient. To the extent that recent advances in machine learning represent advances toward artificial intelligence, innovation would accelerate more. Demis Hassabis of Google DeepMind asserted, "Our goal is to solve intelligence, and then use that to solve the other problems in the world." In that way, Erik Brynjolfsson, in his discussion of this chapter at the conference, argued that artificial intelligence—a field of IT—is "The most G of all GPTs [general purpose technologies]."

Furthermore, IT is an input to other industries. Jorgenson, Ho, and Stiroh (2005) examine how IT impacted productivity in the 1990s. They examine differences between IT-producing and IT-using industries. They document a large increase in the productivity of IT-producing industries. This increased productivity then led to a substantial reduction in the (quality-adjusted) cost of IT. In turn, the reduced cost led to a productivity increase downstream. IT-using industries produced more efficiently with the same inputs, because the inputs became much less expensive. This role of IT as a key input into other industries continues today, though effective adoption of IT depends on complementary innovation by the using firm (Bresnahan and Greenstein 1996; Bresnahan and Yin 2017).

Table 2.1 shows the top 10 patenters in US patent data by half decade since 1976. It is suggestive of the increasing importance of innovation in IT to the broader economy. Between 1976 and 1980, just four of the top 10 patenters were also top patenters in IT, as defined by the "Computers and Communications" patent category. Those include RCA and the US Navy,

Table 2.1   Top 10 patenters by 5-year period

1976–80	1981–85	1986–90	1991–95	1996–2000	2001–05	2006–10
GE	GE	**GE**	**IBM**	**IBM**	**IBM**	**IBM**
AT&T	**IBM**	**GM**	**Motorola**	**Micron**	**HP**	**Microsoft**
IBM	**AT&T**	**Kodak**	GE	**Lucent**	**Microsoft**	**Qualcomm**
Westinghouse	Westinghouse	**IBM**	**Kodak**	**Intel**	**Intel**	GE
RCA	Dow Chemical	Dow Chemical	**GM**	**HP**	Micron	**AT&T**
USA/Sec. Navy	DuPont	DuPont	**AT&T**	**Motorola**	GE	**Intel**
DuPont	**GM**	**AT&T**	**Xerox**	GE	Texas I	**HP**
GM	Mobil	**Motorola**	**Texas I**	Kodak	**Cisco**	Honeywell
Dow Chemical	**RCA**	Westinghouse	3M	**AMD**	Honeywell	**Apple**
Phillips Petro.	Allied Chemical	Allied Signal	DuPont	Xerox	**Broadcom**	Micron

neither of which was an IT-focused company. By 2006–2010, seven of the 10 were top patenters in that category, and one of the remaining three, Micron, makes computer memory products.

Despite this evidence of continuing innovation in IT and its implications for innovation and productivity in IT-using industries, there is simultaneously evidence of a productivity slowdown in the US and in other OECD countries (e.g., Brynjolfsson, Rock, and Syverson 2021; Syverson 2017). Various reasons have been given for this recent productivity slowdown, including mismeasurement, lags in benefits due to need for costly implementation and complementary adjustments, as well as market concentration that may dissipate the benefits of productivity improvements (Brynjolfsson, Rock, and Syverson 2021). Moreover, there is evidence that the benefits of increasing innovation in, and pervasiveness of, IT has not been shared equally across firms, individuals, and regions (Autor et al. 2020; Brynjolfsson and McAfee 2014; Forman, Goldfarb, and Greenstein 2012).

Given the centrality of IT to innovation and recent concerns that the benefits of IT innovation are being captured by a subset of the economy, we study the concentration of innovation in IT over time. By studying trends in US patenting, we provide evidence that is suggestive of an increase in concentration in inventive activity in IT innovation. We measure concentration in two ways: firm level and location level. Specifically, we document trends in patenting concentration over time and across patent categories. We calculate Gini coefficients by firm and by location, annually from 1976 to 2010. We document trends in the fraction and geographic concentration of patents by first-time inventing firms and by individual inventors. Some trends are general, but the focus of our argument is on those specific to IT.

Our empirical results depend on our definition of IT and the data we have available. The dictionary definition of IT is: "The technology involving the development, maintenance, and use of computer systems, software, and networks for the processing and distribution of data" (Merriam-Webster 2020). *The Handbook of the Economics of Information Systems* (Hendershott and Zhang 2006) defines it as "the hardware and software used in the processing and communication of information." Our focus on innovation and inventive activity in IT focuses but also narrows our analysis in several ways. In particular, we measure inventive output using patents. Identifying IT inventions in the patent data is difficult, as highlighted by Graham and Mowery (2003), Bessen and Hunt (2007), Hall and MacGarvie (2010), and others. We define innovations in IT using the classification systems initially developed and described in Hall, Jaffe, and Trajtenberg (2001). We think are our results are suggestive of a broad and important phenomenon that requires further exploration. We discuss the limitations of this definition in detail below.

Firm concentration in patenting could arise for several reasons. One is due to concentration in output markets. A large and still-growing literature has

documented an increase in market concentration over the past few decades and its implications, in some cases highlighting trends in IT-intensive industries. De Loecker, Eeckhout, and Unger (2020) document a rise in markups and an increase in market share across a wide range of US industries. Eggertsson, Robbins, and Wold (2018) take a macroeconomic perspective and argue that increased market power and high profits have caused a decline in labor share. Autor et al. (2017, 2020) demonstrate a connection between a rise in superstar firms and a decline in the labor share. Superstar firms are able to take advantage of globalization and technological change facilitated by IT, and such firms increasingly dominate their industries. The documented increase in market concentration has therefore been blamed for the recent rise of inequality in the US and elsewhere (Furman and Orszag 2015) and for a decline in investment in real and intangible assets (Gutiérrez and Philippon 2017). Andrews, Criscuolo, and Gal (2019) identify a divergence in productivity between the most productive firms and the rest of the distribution, and note that this trend is strongest within ICT services. Both Gutiérrez and Philippon (2017) and Andres, Criscuolo, and Gal (2019) review a broad literature that documents this increase in concentration.

While the line of work cited above has documented increased concentration across the economy, there may be features that are specific to IT that lead to increases in concentration. Shapiro and Varian (1998) highlighted a different set of forces leading to concentration in the IT industry. Emphasizing software, they note that "information is costly to produce but cheap to reproduce" (p. 21). High fixed costs and low marginal costs lead to concentration. Furthermore, they highlight the role of positive feedback loops or network externalities. They note that "positive feedback makes the strong grow stronger" (p. 174). This positive feedback loop is particularly prevalent in many IT contexts, particularly for digital marketplaces. A rich literature (e.g., Einav, Farronato, and Levin 2016; Jullien and Pavan 2019) has emphasized a potential connection between market power and the rise of online marketplaces in advertising (Google, Facebook), goods (Amazon, Ebay), and services (Uber, Airbnb, Upwork). The Stigler Committee on Digital Platforms produced a report that summarized many of these issues (Stigler Center for the Study of the Economy and the State 2019). This documentation of an increase in concentration in IT contexts has led to regulatory attention to the largest IT firms, including Google, Facebook, and Amazon; however, it is important to recognize that antitrust attention to IT has existed for decades, for example, in the 1970s IBM case and the 1990s Microsoft case.

The use of IT as an input to production in other industries can also lead to concentration. Investments in IT are often accompanied by complementary innovation and organizational change (e.g., Aral, Brynjolfsson, and Wu 2012; Bresnahan, Brynjolfsson, and Hitt 2002; Bresnahan and Greenstein 1996). Historically these investments have required substantial fixed

costs and have been shown to have the highest payoff in large organizations (Tambe and Hitt 2012; however, for a recent counterexample, see Jin and McElheran 2018). These investments lead to a stock of intangible capital (Tambe et al. 2019). Industries that are characterized by large investments in IT have seen growth in market concentration (Brynjolfsson et al. 2008; McAfee and Brynjolfsson 2008).

Sutton (1998) highlighted how technology can lead to concentrated market structure through endogenous sunk costs. Specifically, as firms compete by investing in R&D, it becomes harder and harder for new firms to enter. The investment required to achieve the same quality as the leading firms is too high. As a consequence, a relatively small number of firms can dominate the market. IT is an R&D-intensive industry. This is especially true in hardware, but also for some aspects of software. Therefore, we expect the forces Sutton highlighted to lead to concentration in IT-producing industries.

Characteristics specifically related to IT may either facilitate or inhibit concentration. For instance, IT products are often composed of subsystems of components that interact with one another through interfaces that are defined by standards. In this environment, industry firms will compete to define standards through which products and technologies work together and also compete in product markets. This can lead to a circumstance of divided technical leadership, in which multiple firms compete to provide key technologies and products (Bresnahan and Greenstein 1999).

However, the changing nature of innovation in IT can also lead to increases in concentration. Innovation in IT has become increasingly software intensive (Andreesen 2011; Arora, Branstetter, and Drev 2013; Branstetter, Drev, and Kwon 2019). However, the strength of formal measures of intellectual property protection, such as patents, are weaker in software than in other fields of IT innovation, such as IT hardware (Cohen, Nelson, and Walsh 2000; Graham et al. 2009). Changes in the strength of patents can create uncertainty for market participants and inhibit well-functioning markets for technology. For example, increases in the strength of software patents and software patenting can give rise to packet thickets that could lead to declines in de novo entry (Cockburn and MacGarvie 2011).

For geographic concentration, there are many reasons we expect invention to agglomerate. Carlino and Kerr (2015) summarize many of these, emphasizing the role of input sharing, labor market matching, and knowledge spillovers, among others.[1] There is recent evidence that the productivity of inventors is higher in technology clusters (Moretti 2019). In prior work (Forman, Goldfarb, and Greenstein 2016), we documented a sharp rise in the share of US patenting in a small number of cities, and particularly in the

1. A large literature examines the competing effects of convergence and agglomeration. We will not attempt to survey it here. For some examples of how agglomeration can impact regional economic performance, see Glaeser et al. (1992); Henderson, Kuncoro, and Turner (1995); and Fernández-Delgado et al. (2014).

San Francisco Bay Area. A similar phenomenon has been documented in medical devices (Foroughi and Stern 2018). These types of agglomeration economies can give rise to superstar cities (Gyourko, Mayer, and Sinai 2013). A few cities have comprised an increasing share of US (and global) output.

Before we proceed with the chapter, we emphasize that this exercise is entirely descriptive. We will not identify why this is happening, whether the trends are robust to other definitions of innovation, or whether the trends in IT explain the overall changes in market concentration, location concentration, labor share, or productivity.

2.2   Data

We use patents granted by the US Patent and Trademark Office (USPTO) as our measure of invention. Because of the delay between patent application and grant date, we date patents using the year of application. Our starting point is the data provided by the UPSTO through the PatentsView program (www.patentsview.org). We have data on patents granted between 1976 and 2018, and our analysis dataset includes patents with application dates between 1976 and 2010.

To assess trends on IT patents compared to other patents, we use the six patent categories defined in Hall, Jaffe, and Trajtenberg (2001): Chemical; Computers & Communication; Drugs & Medical; Electrical & Electronic; Mechanical; and Other. We consider the Computers & Communication category to represent IT. For some analysis, we look at subcategories related to IT, specifically Communications; Computer hardware & software; Computer peripherals; Information storage; Electronic business methods & software; and Semiconductor devices.

The Hall, Jaffe, and Trajtenberg (HJT) approach is a widely used means to categorize patents based on technology. However, because of recent changes to the patent data, it imposes some limitations on our ability to observe recent trends in our data. The HJT categorization is based on the US Patent Classification (USPC) system. Beginning in 2010, the European Patent Office and USPTO initiated the Cooperative Patent Classification System (CPC), and patents granted after 2015 may no longer have a USPC class and so similarly have no HJT category. Given the lag between the patent application and patent grant dates, we end our sample with patents applied for in 2010 to mitigate truncation bias arising from patents that were applied for and granted after 2010 but were not assigned a USPC class. Even with this sample end date, a small fraction of patents in our sample did not receive a USPC class because of a lengthy application-grant delay.

We focus on patents because they are available in a consistent form over time and across categories. Patents have been shown to provide a useful measure of a firm's intangible stock of knowledge (Hall, Jaffe, and Trajtenberg 2005). Their limitations are well known. Not all patents meet the USPTO

criteria for patentability (Jaffe and Trajtenberg 2002). Not all inventors seek to patent, and many use alternative means to appropriate value from their inventions. In particular, for our purposes, the propensity to patent innovations related to IT is thought to be different from other technology sectors. Cohen, Nelson, and Walsh (2000) note that IT hardware firms (such as semiconductor and communications equipment) report that patenting was effective at protecting about one-quarter of their product innovations in comparison to secrecy, which was effective at protecting one-half of product innovations. There is evidence this may have changed over time, however. In a more recent survey focused on entrepreneurial firms, Graham et al. (2010) note that venture-backed IT hardware firms report that patenting is at least as important as secrecy. However, the same survey notes that among software startups, patenting was the least important among all appropriability strategies (Graham et al. 2010).

Furthermore, the propensity to patent has changed over time during our sample (e.g., Hall and Ziedonis 2001). This was particularly the case for patents related to software, which grew rapidly toward the end of our sample period due to legal changes that strengthened the legal rights of patents in this area (e.g., Graham and Mowery 2003; Hall and MacGarvie 2010). It was only after our sample ends that the *Bilski* and *Alice* cases led to a decrease in the propensity to patent software and business processes. Our approach will lead to bias in our results if large firms are more likely to patent relative to others over time in IT relative to other industries.

We map patents to firms based on several sources. First, we map patents to the CRSP (Center for Research in Security Prices) "permco" list of publicly traded firms using a mapping generously provided to us by the authors of Kogan et al. (2017) and Stoffman, Woeppel, and Yavuz (2019). Further details on the construction of that data are provided in these papers. The method provides a consistent measure of patenting in publicly traded firms over time. For the remaining patents, we grouped patents into organizations based on names provided in the PatentsView data. Our starting point is the disambiguated Assignee names in those data. Then, following procedures detailed in Kogan et al. (2017), we compared assignee names by calculating the Levenshtein edit distance between them. If one assignee name is close to another that is associated with many more patents, then the more common assignee name is substituted for the less common one. This procedure will lead to biased estimates of the number of patents assigned to firms when, for example, patents are assigned to subdivisions of firms with different names and when firms change their names over time. The procedure will influence our results if these events are disproportionately likely to happen in firms that produce IT patents relative to those that patent in other technological areas.

Our primary means of mapping patents to counties is based on the mapping provided in the PatentsView.org data. In cases where this mapping is

unavailable, we used the longitude and latitude provided by the USPTO and the Stata program GEOINPOLY (Picard 2015) to map the locations to counties.

For most of the analysis that follows, we do not weight by citations. For multi-author patents, we divide by the number of authors. For example, if a patent has one author in the Bay Area and two authors in Boston, it would count as 1/3 of a patent in the Bay Area and 2/3 of a patent in Boston. Our results are generally robust, and often stronger, using 3-year and 5-year citation-weighted measures. In the few instances where the citation-weighted results differ qualitatively from the counts, we show both. Otherwise, we focus on the counts.

Our data contain a total of 2,448,280 patents. In 1976, 41,122 new patents were issued by the USPTO. At the peak of our data in 2007, there were 107,744 patents.

We present our results at the year level, as aggregated values over the 35 years from 1976 to 2010 inclusive. This is therefore a descriptive exercise that tests whether the results are consistent with increasing concentration of patents in larger firms over time, for patents related to IT compared to other technological areas. We have not determined the primary cause(s) of the observed patterns.

We measure concentration using Gini coefficients. The Gini coefficient is a measure of statistical dispersion. While typically used to measure economic inequality, it is also a useful measure of concentration (Giorgi 2019). Unlike the Hirschman-Herfindahl index, the Gini coefficient captures whether there are many observations that have very little share. A value of 0 means perfect dispersion, and a value of 1 means perfectly concentrated. In general, a higher Gini coefficient means higher concentration.

One weakness of the Gini coefficient as we use it in the context of patenting is that it will not capture firms with zero patents. In other words, our measures condition on patenting. This will bias our results if the increase in the number of firms patenting over time systematically decreases the Gini coefficient. This is not the case in our data, as the top handful of firms and counties represent an increasing share of patenting, even as the number of firms and counties with at least one patent increases over time.

Overall, these data give us a sense of the general patterns in the concentration of patenting by firm and location over time.

2.3   Results

We present five key results. We compare patenting in Computers and Communications to other HJT categories. In some cases, for brevity, we will refer to patenting in Computers and Communications as "IT patenting." We first show that firm concentration in IT patenting is increasing over time and then show that geographic concentration in IT patenting has similarly grown. We
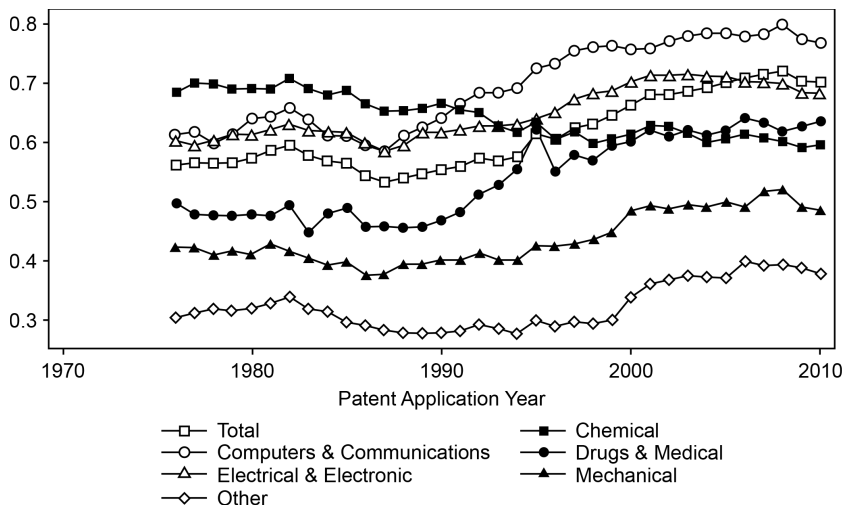
Fig. 2.1   Firm-level concentration in IT patenting, Gini for firm concentration

then turn to an analysis of first-time patenters, showing that the percentage of patents coming from new firms has declined over time, and we show that there has been an increase in the geographic concentration of IT patenters. Last, we further probe our earlier results by showing the increases in firm and location concentration are robust across subcategories of IT patents.

Firm concentration in IT patenting is increasing over time. Figure 2.1 shows that the Gini coefficient for patents in the Computers & Communications patent category fell from 0.66 to 0.59 from 1983 to 1987, an 11 percent fall. This coincided with the diffusion of decentralized computing devices like personal computers. The Gini has been almost continually rising since then, though the rate of growth has slowed in recent years: the Gini rose to 0.77 in 2010. The Electrical & Electronic category has followed a similar pattern, though the decline in the 1980s was not as pronounced and the subsequent rise not as great. Other categories of invention have increased over the same time period. In particular, Drugs & Medical rose from 0.45 to 0.63 between 1988 and 2010. However, what is unique about Computers & Communications was the pronounced fall followed by significant rise observed over our sample period. This rise was largest in the 1990s.

Figures 2.2a and 2.3a show that the total number of patents and patenters (patenting firms) in Computers & Communications is growing, even as concentration also increases. Based on total patents, Computers & Communications became the largest patent category in the 1990s, and it is now by far the largest category. Some of this rise is driven by an increasing propensity to patent, as highlighted by Hall and Ziedonis (2001). Figures 2.2b and 2.3b show these values weighted by citations over the 3 years following
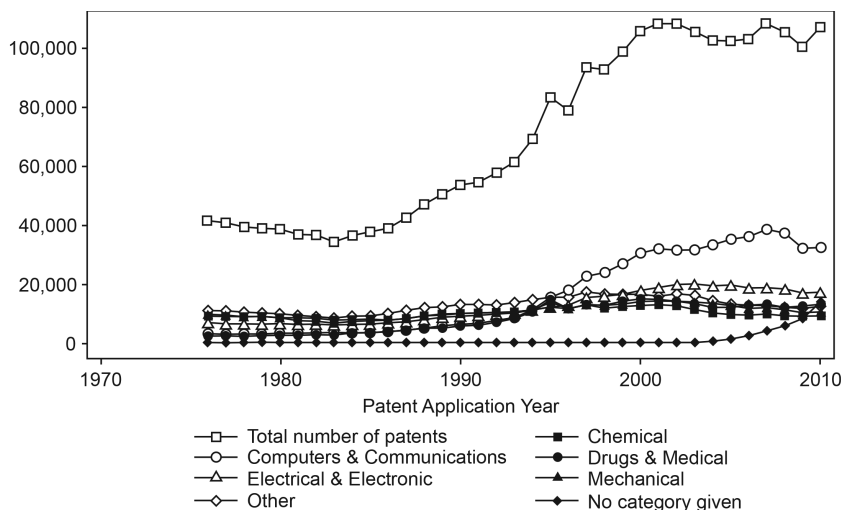
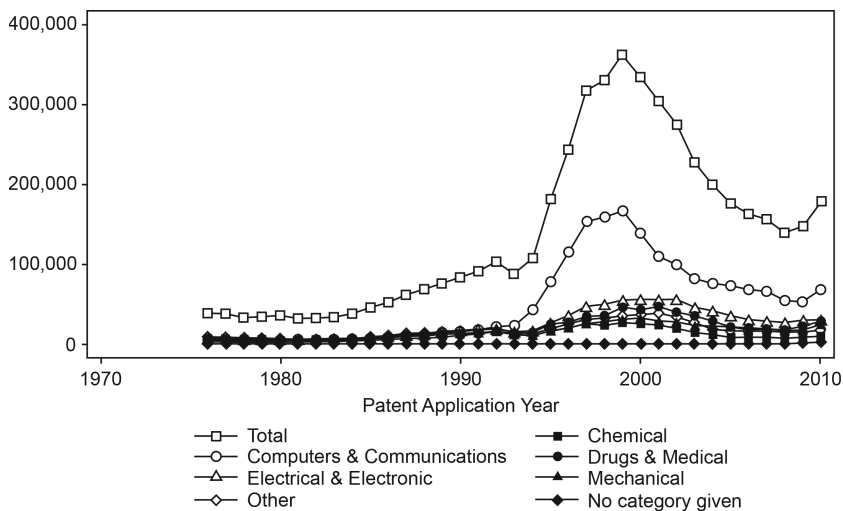**Fig. 2.2a   Total patents**

Fig. 2.2b   Total patents, weighted by 3-year forward citations

the application. These citation weights are a proxy for quality (Hall, Jaffe, and Trajtenberg 2005). Comparing figures 2.2a and 2.2b, until 2000, the patterns for the citation-weighted data in Computers & Communications look similar to non-citation-weighted data, with the number of patents in both categories increasing over time. After 2000 they diverge, however. While the total number of citation-weighted patents declines after 2000, the number
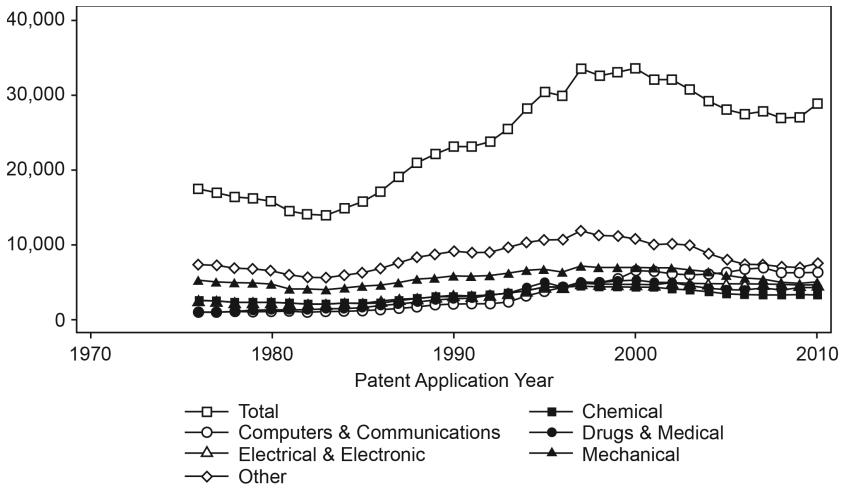
Fig. 2.3a   Number of patenters (firms and individuals)
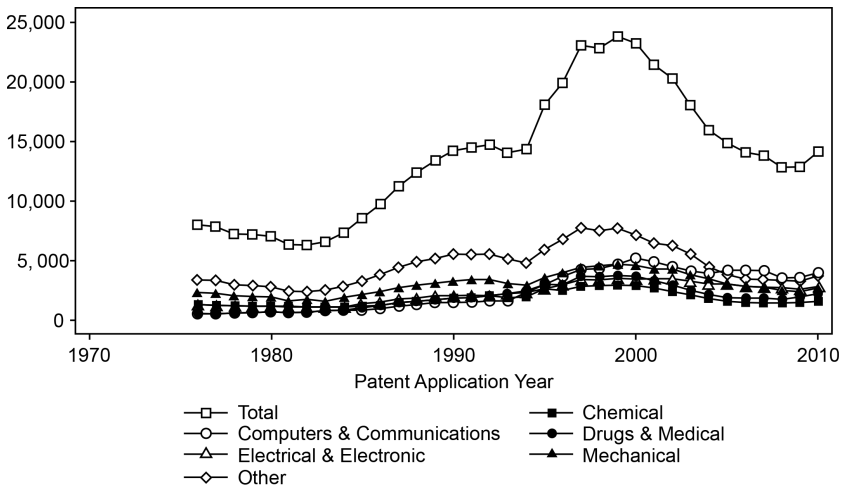

Fig. 2.3b   Number of patenters (firms and individuals), weighted by 3-year forward citations

of citation-weighted patents in Computers & Communications experiences the sharpest absolute and relative declines over time. Nevertheless, the difference between IT patents and other patents remains. IT patents continued to represent the largest share of patenting, whether citation weighted or not.[2]

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2. The other figures in this chapter show similar trends for counts and for citation-weighted measures. Therefore, to keep the paper streamlined, we show only the counts.
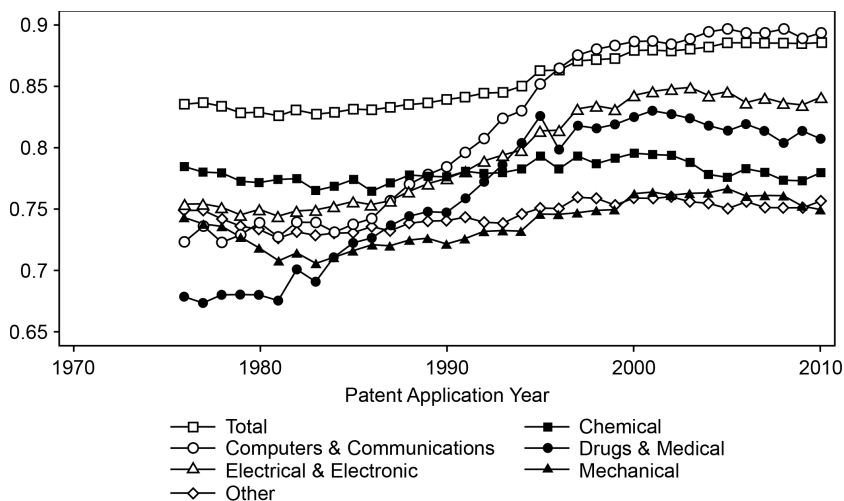
Fig. 2.4   Location-level concentration in IT patenting over time, Gini for location concentration

We further note that in figures 2.2a and 2.2b, some patents have no technology category. This is because of the transition from USPC to CPC codes mentioned in section 2.2. We provide these results to demonstrate how this transition influences our data. Because our analysis requires comparing patents across technology categories, in other figures, we drop these patents from our sample.

Geographic concentration of IT patenting has grown. Figure 2.4 shows the increasing Gini by location over time. Location is defined by county, and so there has been a large increase in location concentration in Computers & Communication since 1985. This increase is particularly pronounced in the 1990s. This result is similar to Forman, Goldfarb, and Greenstein (2016) who found a large increase in IT patenting in the San Francisco Bay Area in particular. As was the case with firm concentration, we see similar but more muted patterns in Electrical & Electronic and a similarly strong trend of increases in concentration among Drugs & Medical. Of course, if invention is increasingly concentrated in fewer firms then firm concentration could contribute to geographic concentration if firms have a limited number of geographic centers of invention (Ellison and Glaeser 1997). We explore this possibility in further detail below.

Decline in new patenters 2000–2010. We now explore changes in the number of new (first time) patenters. Figures 2.5a–c show a steady decline in new patenters over time. These figures compare the share of new patents that are coming from new firms for each year. Since our data begin in 1976, all patenters in 1976 are new, and the subsequent decline across all catego-
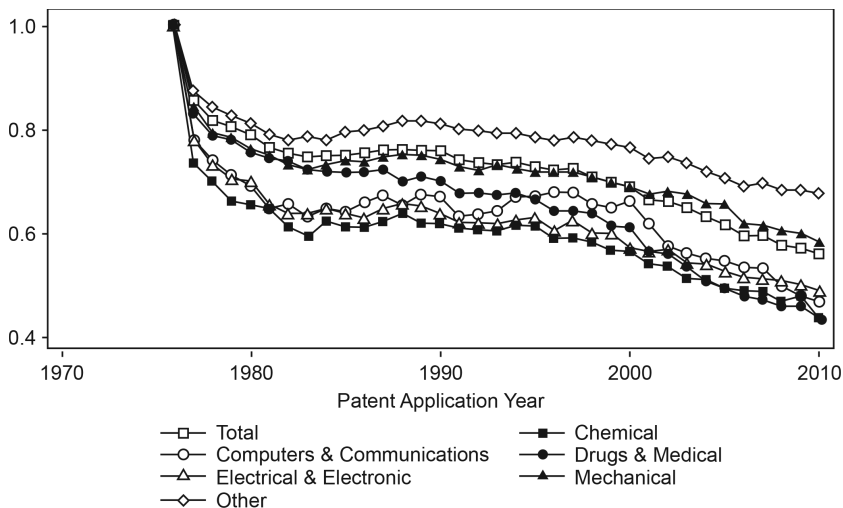
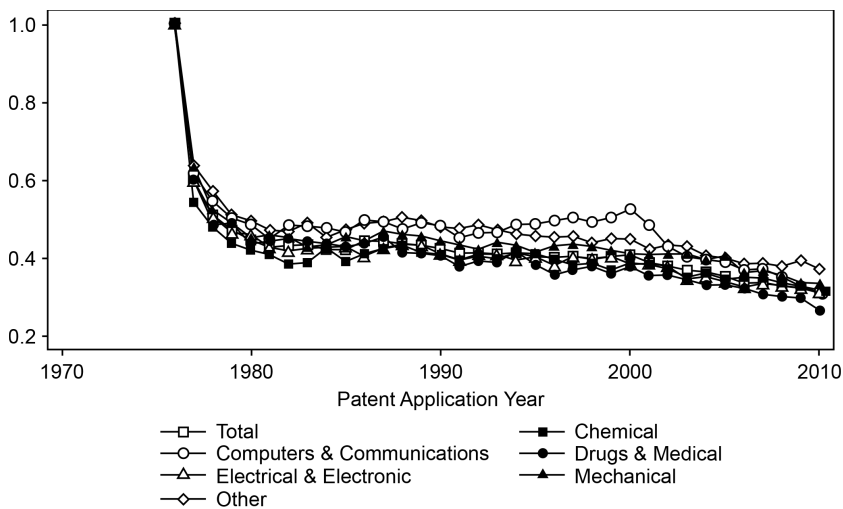**Fig. 2.5a   Percentage of new patenters over time**

Fig. 2.5b   Percentage of new patenting firms, not including individuals, over time

ries of invention subsequently is in part mechanical. Figure 2.5a shows all patenters, and figure 2.5b excludes individual patenters and focuses on firms only. Figure 2.5c shows the individual patenters only. All three figures reveal similar patterns.

The share of patenters from new firms in Computers & Communications remained fairly stable between 1980 and 2000. After that, it declined
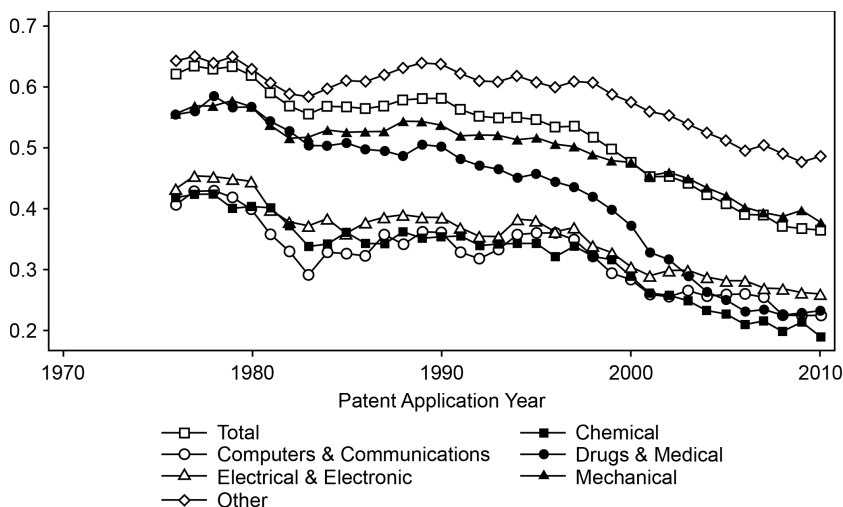
Fig. 2.5c   Percentage of individual patenters over time

sharply. Beginning in the late 1990s, a series of court decisions and action by the USPTO changed perceptions about the patentability of software.[3] As a result, the sharp decline post-2000 could be shaped by changes in the composition of patenting in Computers & Communications during this period. However, the percentage of new patenters continued to fall until the end of our sample period. Put differently, the surprise here is that IT didn't fall in 1980–2000, rather that it did fall thereafter.

Increased geographic concentration of new IT patenters. Figures 2.6a–b show that the geographic concentration of new IT patenters has grown over time. In other words, the increasing geographic concentration of patenting shown in figure 2.4 is not mechanically a result of the increased firm-level concentration of patenting. New firms are also geographically concentrated. Figure 2.6a shows all first-time patenters. Figure 2.6b shows firms only.

Similar results across IT subcategories. Figures 2.7a–b shows that the general trends in concentration by firm and concentration by location are robust across the different categories of Computers & Communications: Communications, Computer hardware & software, Computer peripherals, Information storage, Semiconductor devices, and Electronic business methods & software.

Figure 2.7a shows firm-level concentration. For Electronic business methods & software, results prior to the late 1990s are difficult to interpret because of the uncertainty of the patentability of software. However, between 2000 and 2010, this category shows the fastest rate of growth in concentration, from 0.53 in 2000 to 0.60 in 2010. Semiconductor devices has the highest

3. See Hall and MacGarvie (2010) and Cockburn and MacGarvie (2009) for further details.
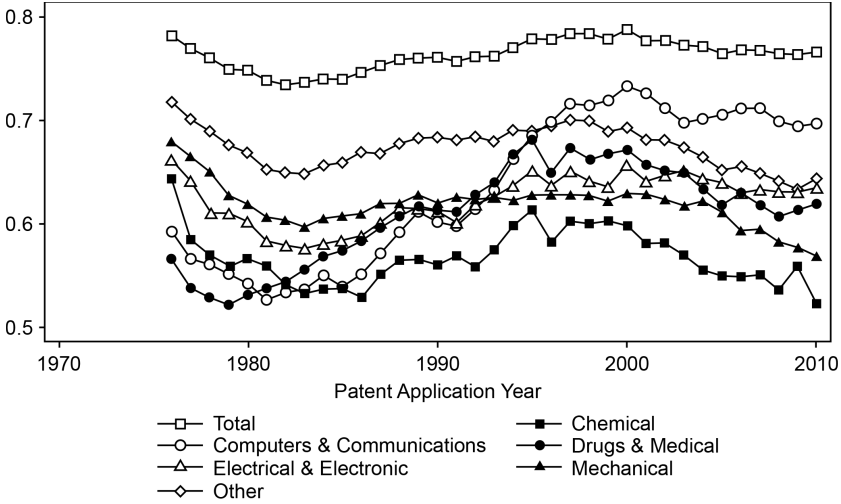
Fig. 2.6a   Geographic concentration (Gini by location) of first time patenters over time, firms and individuals
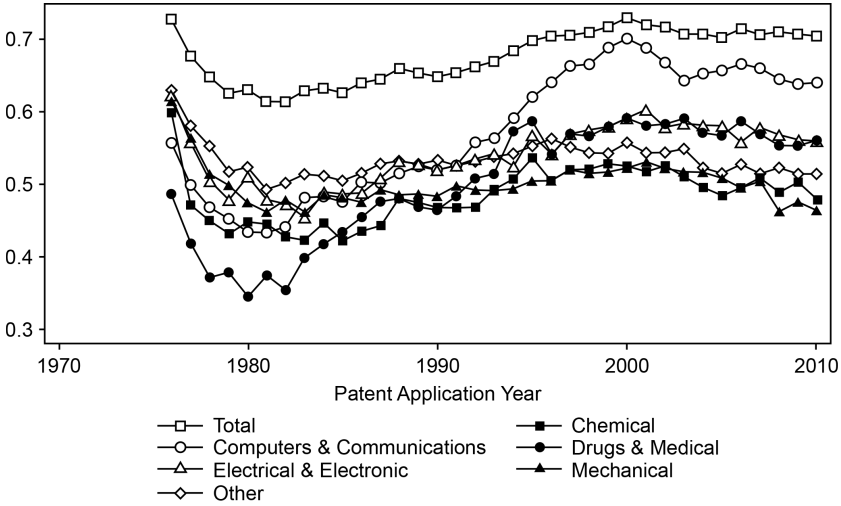

Fig. 2.6b   Geographic concentration (Gini by location) of first time firm patenters over time

Gini coefficient throughout most of the sample, but it declines between 2000 and 2010. Figure 2.7b shows that the increases in the Gini coefficient by location hold across all subcategories of IT.

Figure 2.8 provides context, showing the trend in total patents over time for each subclass. It suggests that the category of Electronic business methods & software grows from effectively zero in mid-1990s to comprise a meaningful share of all IT patents.
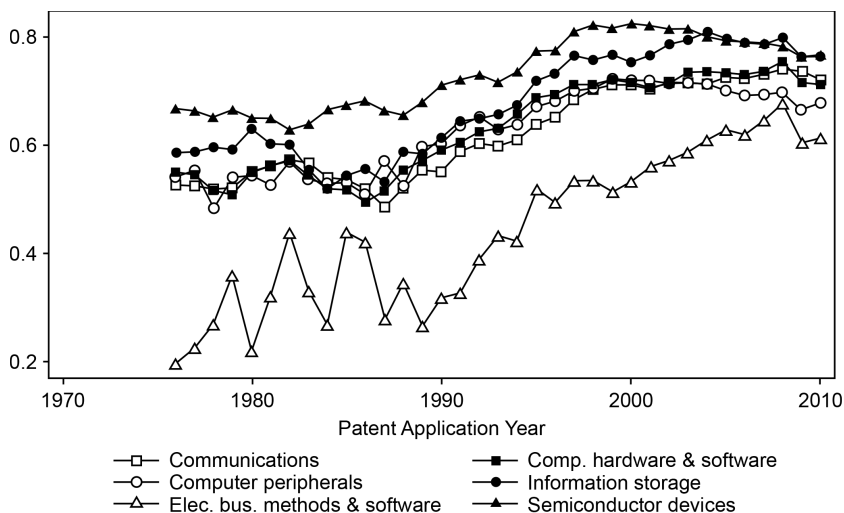
Fig. 2.7a   **Firm-level concentration (Gini by firm) over time by IT subclass**
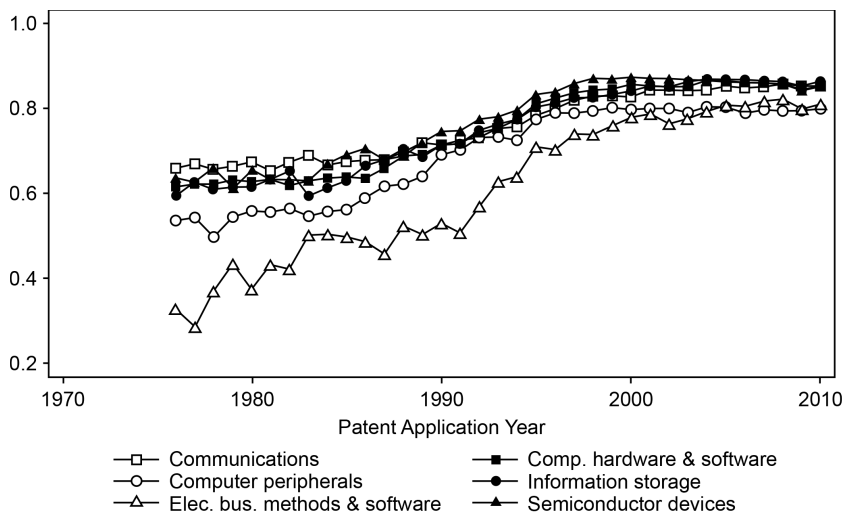
Fig. 2.7b   **Location-level concentration (Gini by location) over time by IT subclass**

2.4   Hypotheses on the Rise of Concentration

The above analysis presents a puzzle. We have documented that the firm-level and location-level concentrations of IT patenting have risen over time, particularly since 1990. Here we present several hypotheses that could explain this rise. In this chapter, we will not test these hypotheses, leaving that for future work.

Fig. 2.8   Total patents over time by IT subclass

2.4.1   Why Is Firm-Level Concentration Rising?

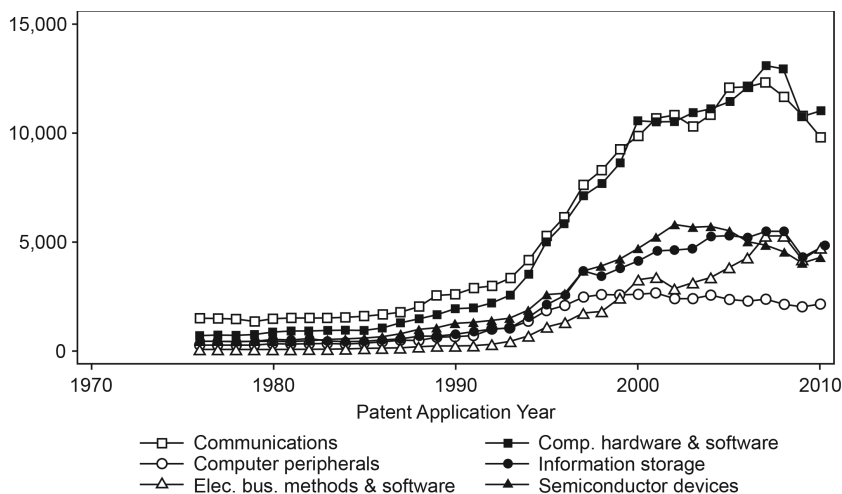We identify 10 possible (sometimes overlapping) reasons that we measure an increase in firm-level concentration in IT patenting over time:

1. *Network externalities in IT*: Network externalities are important for a variety of IT applications (Shapiro and Varian 1998). If the value of a technology rises with the number of users, either directly as for a communication technology or indirectly as for online platforms, then this can lead to an increase in industry concentration (e.g., Armstrong 2006; Katz and Shapiro 1985). If these network externalities have been increasingly important to IT over time (or if interoperability and common standards have become less important), then this could lead to a concentration of the industry overall and a concentration in firm-level IT patenting.

2. *Superstar effects in demand for IT*: IT has lowered the cost of searching for information (Goldfarb and Tucker 2019; Shapiro and Varian 1998), which has made comparison across products easier. Combined with low marginal costs, this can lead to a superstar effect, in which a small number of firms that offer superior quality dominate (Bar Isaac, Caruana, and Cuñat 2012; Rosen 1981).

3. *High fixed costs*: In addition to superstar effects, industries with high fixed costs and low marginal costs have barriers to entry and a minimum efficient scale. As Shapiro and Varian (1998) emphasize, information goods have high fixed costs and low marginal costs. Many IT products are information goods. Furthermore, high fixed cost and low marginal cost are also characteristics of IT hardware. Generally, this will lead to a barrier to entry

and a relatively small number of firms. To the extent that fixed costs have risen over time, this could explain the increased concentration.

4. *Endogenous sunk costs*: Sutton (1998) emphasized that the cost structure of an industry is endogenous. As leading firms compete with one another in R&D, an increasing amount of resources is required for a new entrant to compete. These endogenous sunk costs increase concentration of an industry over time. As the leading IT firms invest in R&D, it may have become harder for new entrants to join the industry. In this way, competitive pressure among the leading firms can lead to the concentration of an industry over time.

5. *Intangible capital*: There has been a sustained increase in the importance of intangible capital over time. This increase in the role of management practices, business processes, and firm-specific employee skills is not captured in standard measures of investment (Corrado, Hulten, and Sichel 2009). This growth is particularly pronounced among firms using IT (Brynjolfsson et al. 2008; Tambe et al. 2019). Intangible capital represents a fixed cost (and perhaps an endogenous sunk cost). It is also difficult to imitate; there is no easy strategy for a new entrant to invest in generating the intangible capital needed to compete. Intangibles can therefore lead to firm-level concentration among firms using IT. These firms may also create patents that use IT as a critical input (Branstetter, Drev, and Kwon 2019).

6. *The burden of knowledge*: Jones (2009) demonstrated that innovation has been getting harder over time. Similarly, Bloom et al. (2020) demonstrated that the productivity of innovation is falling. New ideas are getting harder to find. While these ideas have not been shown to be specific to the IT industry, they would increase the costs associated with patenting and might therefore benefit large firms over small.

7. *Anticompetitive behavior*: The Stigler Report (Stigler Center for the Study of the Economy and State 2019) emphasizes the increasing concentration of many aspects of the IT industry. More generally, the IT industry has been the subject of antitrust scrutiny for decades, with cases against IBM, AT&T, and Microsoft. If antitrust scrutiny and merger control have become more lenient over time in the IT industry (e.g., Gutiérrez and Philippon 2017; Valletti and Zenger 2019), then this would lead to increased concentration of the industry generally and therefore increased firm-level concentration of patenting behavior.

8. *Maturity of the industry*: Our data begin in 1976. At that time, the IT industry was relatively new. In the early stages of an industry, it is not unusual for many competitors to enter and then for a few firms to dominate over time (Klepper 2002; Klepper and Graddy 1990). While there is evidence that recent IT innovations have reduced barriers to entry for small firms (Jin and McElheran 2018), these forces may be dominated by the increasing maturity of the industry.

9. *Uncertainty and changes in intellectual property protection*: The strength

of patents historically has been weaker for some inventions based on IT, particularly those based on business methods and software. As we noted above, strengthening of intellectual property protection in software was coincident with an increase in patenting in these categories. This increase in patenting may have made it more difficult for de novo startups to receive financing and enter markets (Cockburn and MacGarvie 2009, 2011). Conversely, uncertainty about the strength of patents can lead to concerns about expropriation of intellectual property assets when startups contract with established firms, making it more difficult for markets for specialized suppliers to develop (Gans and Stern 2003; Gans, Hsu, and Stern 2002).

10. *Bias in our analysis*: The result may be driven by our use of patent data. If the largest firms have become increasingly likely to patent their innovations (however marginal) over time, then this will lead to an increase in measured concentration of patenting without a meaningful increase in the underlying concentration of innovation. This is related to the prior point in that both are based on changes in the patent system. However, the earlier point is about changes in equilibrium outcomes brought about by these changes, rather than mismeasurement of invention caused by our use of patents. Many of our other empirical choices may lead to results that are not robust to other measures of innovation and other measures of patenting. While we have examined robustness to some of these choices, such as citation weighting, our goal has not been to emphasize robustness. Instead, we have focused on identifying a puzzle that warrants further examination.

The above hypotheses are not mutually exclusive. Furthermore, many of them build on the same idea of fixed costs leading to concentration. Overall, the relationship between concentration and welfare depends on the relative importance of these hypotheses. For example, given fixed costs to innovation, increased concentration of innovation may be efficient. Other hypotheses, such as the burden of knowledge, imply that increased concentration and a reduced growth rate for welfare are consequences of other forces. Clearly, if increased concentration is driven by an increase in anticompetitive behavior, then it is welfare reducing.

2.4.2   Why Is Location-Level Concentration Rising?

While there is a significant body of work on location-level concentration in invention,[4] there is less literature that might explain why we see differences in trends in location-level concentration in IT relative to other types of technologies. Therefore, our hypotheses mostly draw on work that has highlighted the reasons for location-level concentration more generally and leave for future work an explanation for why the benefits of concentration might be different in IT. We identify four possible reasons:

4. See, for example, Carlino and Kerr (2015), Audretsch and Feldman (2004), and Feldman and Kogler (2010).

1. *Productivity of inventors in high-tech clusters*: Forman, Goldfarb, and Greenstein (2016) find a general increase in innovation in the San Francisco Bay Area over time and across all patent classes. They suggest that this increase might be due to agglomeration economies in invention. Moretti (2019) provides direct evidence of this, demonstrating that inventors are increasingly productive in high-tech clusters. This could explain the increased location-level concentration of patenting in IT. As a high-tech industry, invention has increased in those clusters, either because investors move to those clusters to be more productive or because the inventors in the clusters become more productive over time (or both).

2. *Agglomeration economies*: More generally, there may be increased agglomeration economies in the IT industry, independent of the productivity of inventors. Forman, Goldfarb, and Greenstein (2012) and Dranove, Garthwaite, and Ody (2014) show that IT adoption is more effective in cities. Outside IT, the increased importance of agglomeration economies between 1980 and 2010 is well documented in the urban economics literature (Duranton and Puga 2004; Glaeser 2012; Helsley and Strange 2014). If industrial activity is increasingly concentrated in a few locations and effective application of IT in using industries is increasingly concentrated in those locations, then IT innovation will be increasingly concentrated.

3. *Firm-level concentration*: For the most part, the hypotheses on the increase in firm-level concentration are unrelated to those on location-level concentration. This hypothesis is an important exception. An increase in firm-level concentration could mechanically increase location-level concentration. If a small number of firms increasingly dominate patenting, and if each firm focuses its patenting in a small number of locations, then the increase in firm-level concentration directly leads to an increase in location-level concentration. If this is the primary reason for increased location-level concentration, the location-level concentration is relatively uninteresting in itself.

4. *Bias in our analysis*: The result may be driven by our use of patent data. As with our analysis of firm-level concentration, to the extent that our measures of increased concentration in patenting are attempts to measure concentration in innovation, then we are limited by what can be learned from patent data. If there is an increased propensity to patent in certain locations over time (particularly in IT), then this increase could drive our result, and it might have little to do with innovation generally.

2.5   Conclusions

We document a change in concentration in patenting at both the firm level and the location level. We also document a decline in the fraction of new patenters from 2000 to 2010, especially in IT. We further find that patenting has become increasingly concentrated in a smaller number of locations. These

patterns are found across different categories of IT, though some evidence suggests that the patterns may be stronger in Electronic business methods & software. These findings complement other recent evidence, found elsewhere, that the effects and incidence of technological change in IT are not shared equally across industries, firms, locations, and people.

These findings are important, because many prominent companies and emerging industries use IT as a critical input or are inherently digital. Furthermore, IT is an input to other inventions. There is rising concentration across firms both in and outside IT. There are reasons to expect IT to lead to concentration. Therefore, maybe IT is to blame. As noted in the introduction, this possibility has recently been more prominently raised in industries that are most easily digitized and that have been affected by digital platforms (Stigler Center for the Study of the Economy and the State 2019). However, there is a long-run trend of increasing use of IT and software in other industries, like manufacturing (Branstetter, Drev, and Kwon 2019), which may accelerate with the increasing diffusion of artificial intelligence (e.g., Cockburn, Henderson, and Stern 2019).

The increasing concentration of software innovation in a smaller number of locations is also important. The tendency for innovation to agglomerate in and across industries, the increasing concentration of innovation in IT, and IT's increasing use as an input in innovation may encourage the development of superstar cities, as documented elsewhere (Gyourko, Mayer, and Sinai 2013).

Increases in firm and geographic concentration will have important implications for the issues surrounding innovation, entrepreneurship, and growth that are the focus of this volume. A rich literature has explored the relationship between competition and innovation (for a review, see Gilbert 2006). Further, as noted at the beginning of this chapter, recent work has highlighted how increases in firm concentration can have important implications for the labor share and corporate investments, both of which have important growth implications. Likewise, increases in firm and geographic concentration could contribute to a rise in income inequality in the US. For economic growth more generally, increased productivity and innovation in this sector are likely to impact growth substantially in the short term. Over time, however, as in other sectors, as productivity improves, we can expect the industry to be a smaller part of overall economic output (Baumol 1967), and the impact of this industry on overall geographic and industrial concentration of economic activity should decline over time.

Our research is subject to several limitations. For one, we use patents as our measure of invention. Patents are a useful way to study concentration in innovation, particularly because they provide a consistent measure that is available over a long time. However, they are less frequently used as a measure of intellectual property protection than in other technologies and settings discussed in this book, and their strength has varied over time, both

inside and outside our sample period. As a result, it is well known that the propensity to patent has varied over time, particularly in software; thus our results must be viewed with some care. Furthermore, our results end with patents applied for in 2010. Thus, our results miss recent developments that may arise because of changes in digitization, artificial intelligence, and cloud computing, among others. It is an open question whether the results are stronger or persist to the present day. Finally, our results are preliminary in the sense that we do not seek to explain why they are happening and what their implications are, if any. In particular, we do not show whether technological trends in IT explain the overall changes in market concentration, location concentration, labor share, or productivity.

Our approach also highlights important limitations to measuring concentration of IT innovation and entrepreneurship going forward. As famously highlighted in Marc Andreessen's statement that "Software Is Eating the World" (Andreessen 2011) and documented across chapters in this volume, innovation that is enabled by IT hardware and software is pervasive across industries. In our study, this pervasiveness made it difficult to identify IT-related patents in the patent system, but the same phenomenon also makes it difficult to identify new firm formation and growth in employment and production that is IT enabled. This occurs not only through the transformation of traditional industries like housing and real estate by de novo software start-up companies, such as Zillow and Redfin (Edward Kung, chapter 11, this volume), but also by attempts by large existing firms like General Electric to become digital businesses.

Despite these limitations, our contribution is to document a new pattern in the time trends in IT patenting. Both firm-level concentration and location-level concentration have increased over time.

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