Concentration and agglomeration of IT innovation and entrepreneurship: Evidence from Patenting[*]

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Abstract

Information technology (IT) matters to prosperity. The top patenters are increasingly IT companies. We use data on US patents to document four trends in IT patenting. First, firm-level concentration in IT patenting is increasing over time. Second, geographic concentration in IT patenting is increasing over time. Third, most technology classes experienced a decline in new patenters from 1980 to 2000. This was not true of new IT patents. Since 2000, the trend in new IT patenters looks like other classes and is declining over time. Fourth, there is increased geographic concentration of new IT patenters. We do not identify the reasons behind these trends nor whether they are related to overall changes in industry concentration, agglomeration, or prosperity.

Key Words: Information technology, patenting, entrepreneurship, entry, innovation

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

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 fifty 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 ten 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.

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 R&D dollar, 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".

Furthermore, IT is an input into 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. This, in turn, 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 1 shows the top ten 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 ten patenters were also top patenters in IT, as defined by the "Computers and Communications" patent category. Those include RCA and the Navy, neither of which was an IT-focused company. By 2006-2010, seven of the ten were top patenters in that category, and one of the remaining three, Micron, makes computer memory products.

Table 1: Top ten patenters by five-year period

1976-80	**1981-85**	**1986-90**	**1991-95**	**1996-00**	**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

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., Syverson 2017; Brynjolfsson, Rock, and Syverson 2019). A variety of 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 2019). 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 (Forman, Goldfarb, and Greenstein 2012; Brynjolfsson and McAfee 2014; Autor et al 2020).

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 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 (2019) 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 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 (Gutierrez 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 that this trend is strongest within ICT services. Both Gutierrez and Philippon (2017) and Andres, Criscuolo, and Gal (2019) review a broad literature that documents this increase in concentration.

While the line of work 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, 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 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 to complementary innovation and organizational change (e.g. Bresnahan and Greenstein 1996; Bresnahan, Brynjolfsson, and Hitt 2002; Aral, Brynjolfsson, and Wu 2012). 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, Hitt, Rock, and Brynjolfsson 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 research & development (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. Information technology is an R&D-intensive industry. This is especially true in hardware, but also in some aspects of software. Therefore, we expect the forces Sutton highlighted to lead to concentration in IT-producing industries.

Characteristics specifically related to information technology may either facilitate or inhibit concentration. On the one hand, 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, Drev 2013; Branstetter, Drev, and Kuan 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, Merges, Samuelson, and Sichelman 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 why 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 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 small number of cities have comprised an increasing share of US (and global) output.

Before we proceed with the paper, we want to 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.

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 data set includes patents with application dates between 1976 and 2010.

In order 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 &

[1] There is a large literature examining 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 et al. (1995), and Delgado et al. (2014).

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 upon 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 upon 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 within our sample do 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 et al. 2005). Their limitations are well known. Not all patents meet the USPTO criteria for patentability (Jaffe and Trajtenberg 2001). 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 et al (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 start-ups patenting was the least important among all appropriability strategies (Graham et al 2010).

Further 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 which 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 "permco" list of publicly traded firms using a mapping generously provided to us by the authors of Kogan, Papanikolaou, Seru, and Stoffman (2017) and Stoffman, Woeppel, and Yavuz (2019). Further details on the construction of that data is provided in these papers. The method provides a consistent measure of patenting within publicly traded firms over time. For the remaining patents we grouped patents into organizations based upon 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. They 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 PTO 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 1 author in the Bay Area and 2 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 three year and five 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, there were 41,122 new patents issued from the PTO. 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 within larger firms over time, in 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 2020). Unlike the Hirschman-Herfindahl index, the Gini coefficient captures whether there are a large number of observations that have very little share. A value of zero 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.

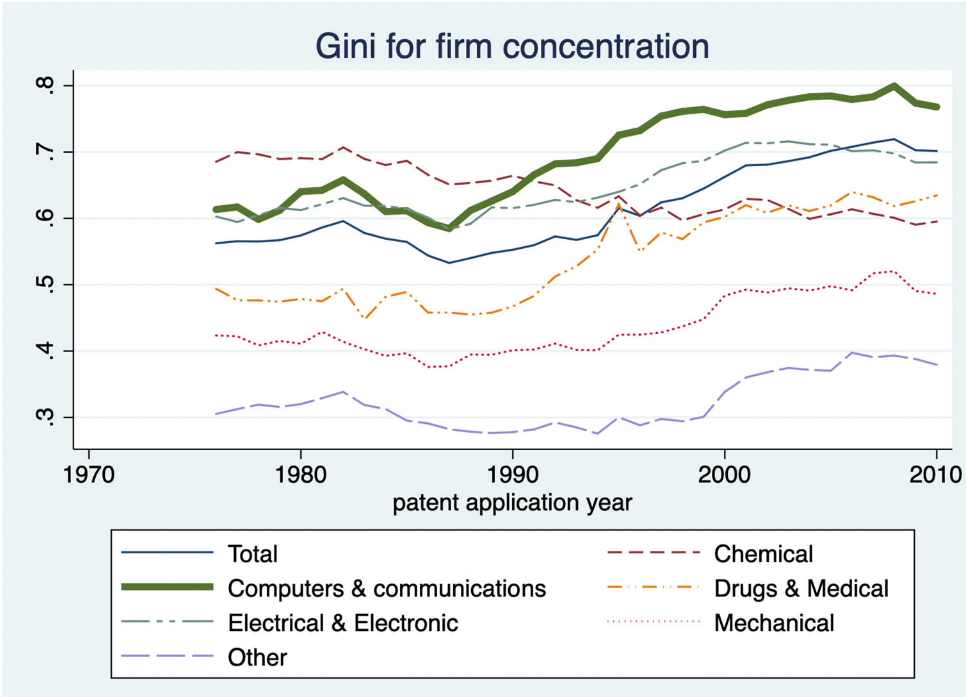
Overall, this data gives us a sense of the general patterns in the concentration of patenting by firm and location over time.

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, then show that geographic concentration in IT patenting has similarly grown. We then turn to an analysis of first time patenters, showing that the percent of patents coming from new firms has declined over time, and 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. In Figure 1 we find 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% 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.

Figure 1: Firm level concentration in IT patenting



Figures 2a and 3a shows 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 is driven by an increasing propensity to patent, as highlighted by Hall and Ziedonis (2001). Figured 2b and 3b show these values weighted by citations over the three years following the application. These citation-weights are a proxy for quality (Hall, Jaffe, and Trajtenberg 2005). Comparing Figures 2a and 2b, until 2000 the patterns for the citation-weighted data in Computers & Communications look similar to non-citation-weighted, with the number of patents in both categories increasing over time. After 2000 they diverge, however. While the total number of citation-weighted patents decline after 2000, the number 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 the represent the largest share of patenting, whether citation-weighted or not.[2]

We further note that in Figures 2a and 2b some patents have no technology category. This is because of the transition from USPC to CPC codes mentioned in the Data section. We provide these results to demonstrate how this transition influences our data. Because our analysis

[2] The other figures in this chapter show similar trends for counts and for citation-weighted measures. Therefore, we only show the counts in order to keep the paper streamlined.

requires comparing patents across technology categories, in other Figures we drop these patents from our sample.

Figure 2a: Total patents

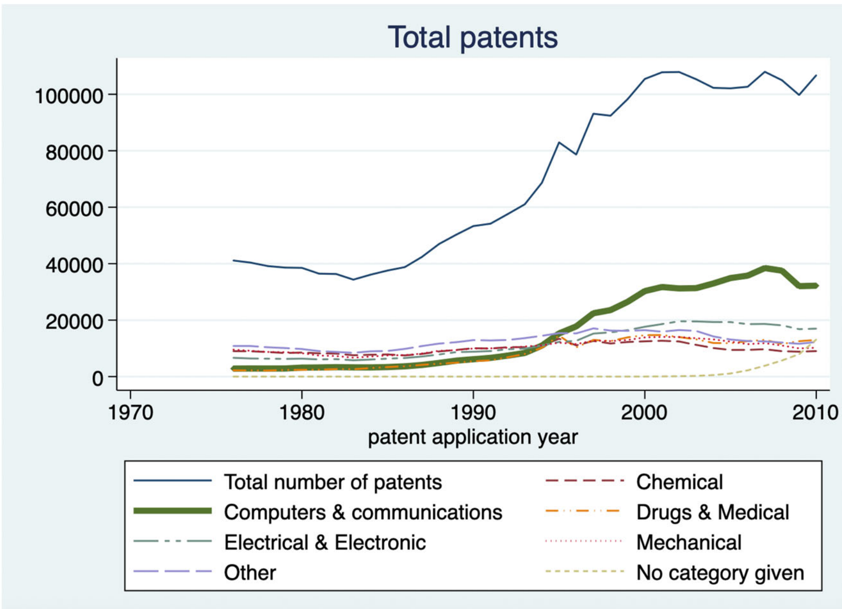


Figure 2b: Total patents, weighted by 3 year forward citations

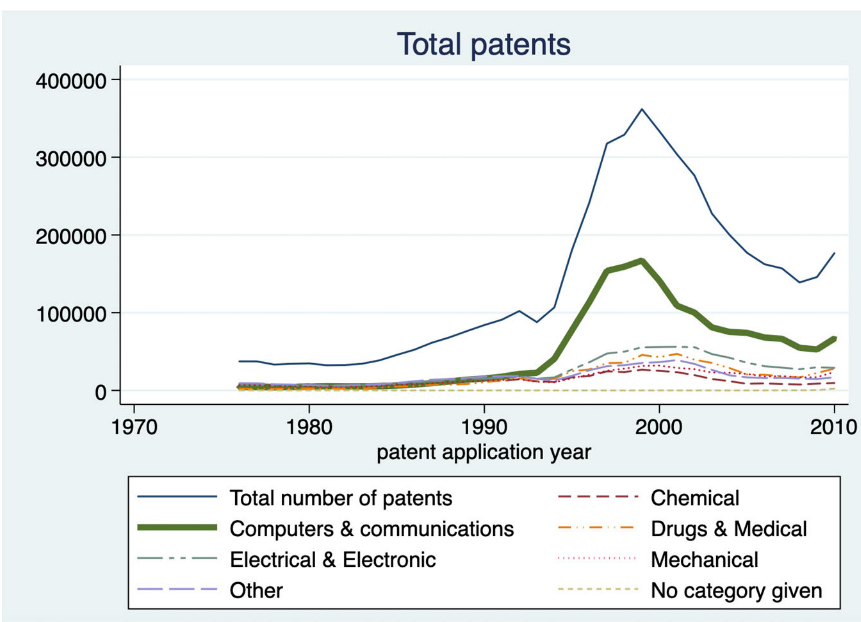


Figure 3a: Number of patenters

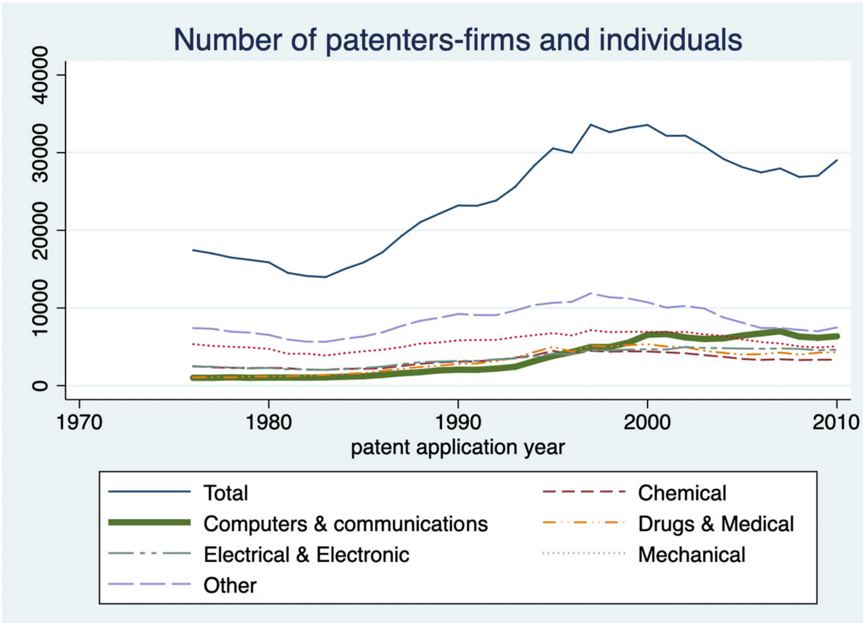
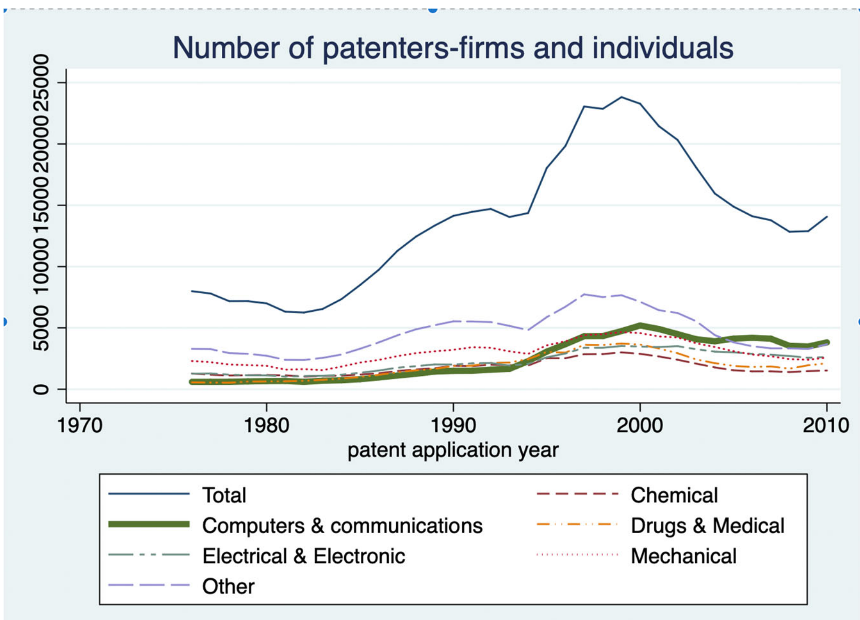
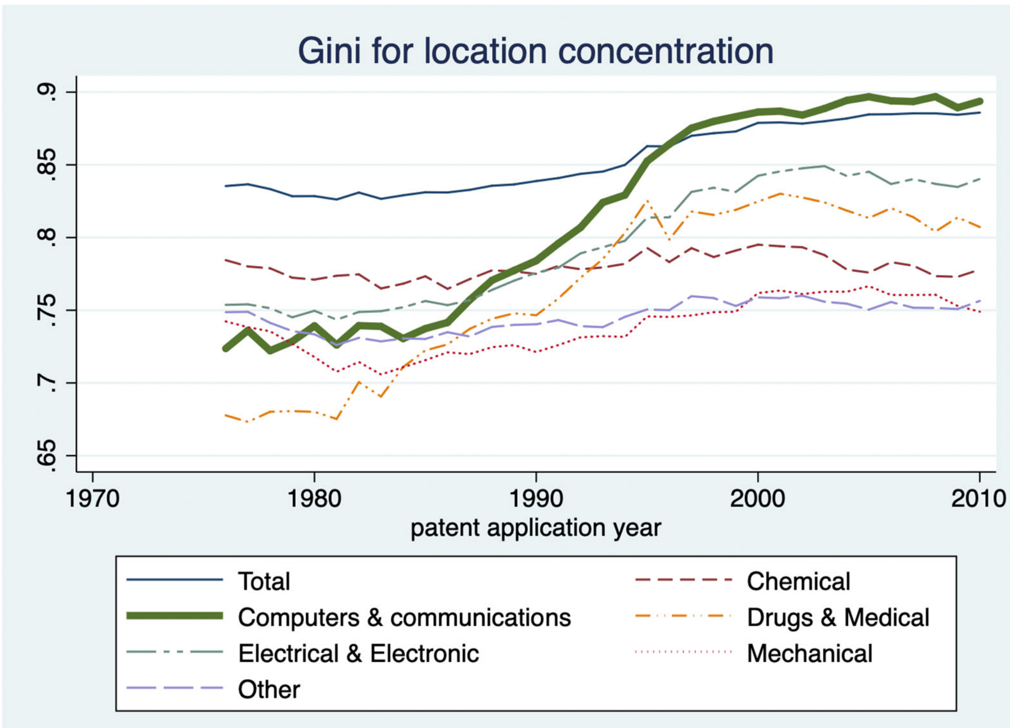


Figure 3b: Number of patenters, weighted by 3 year forward citations



Geographic concentration of IT patenting has grown. Figure 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.

Figure 4: Location-level concentration in IT patenting over time



Examination of new patenters

Decline in new patenters 2000-2010. We now explore changes in the number of new (first time) patenters. Figure 5 shows a steady decline in new patenters over time. It compares 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 categories of invention subsequently is in part mechanical. Figure 5a shows all patenters and figure 5b excludes individual patenters and focuses on firms only. Figure 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 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 time 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 1980-2000, rather that IT did fall after.

Figure 5a: New patenters over time

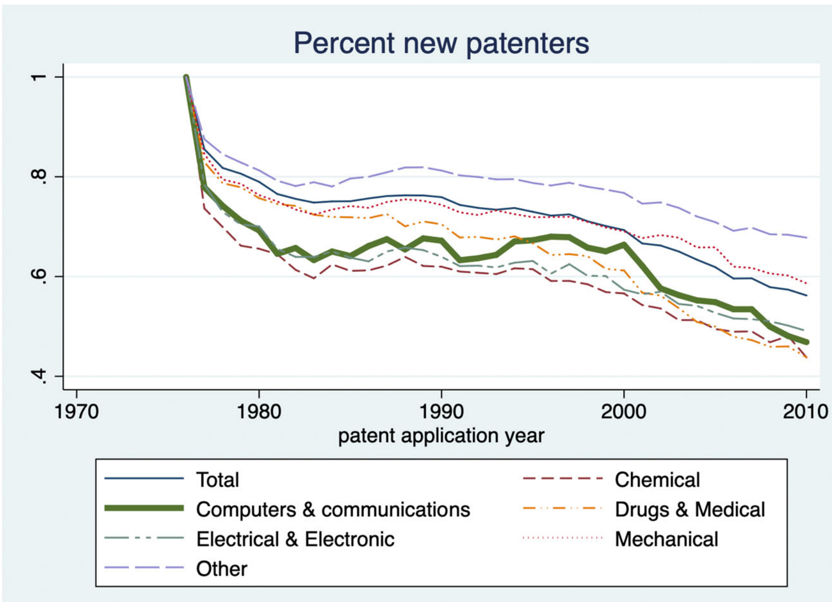
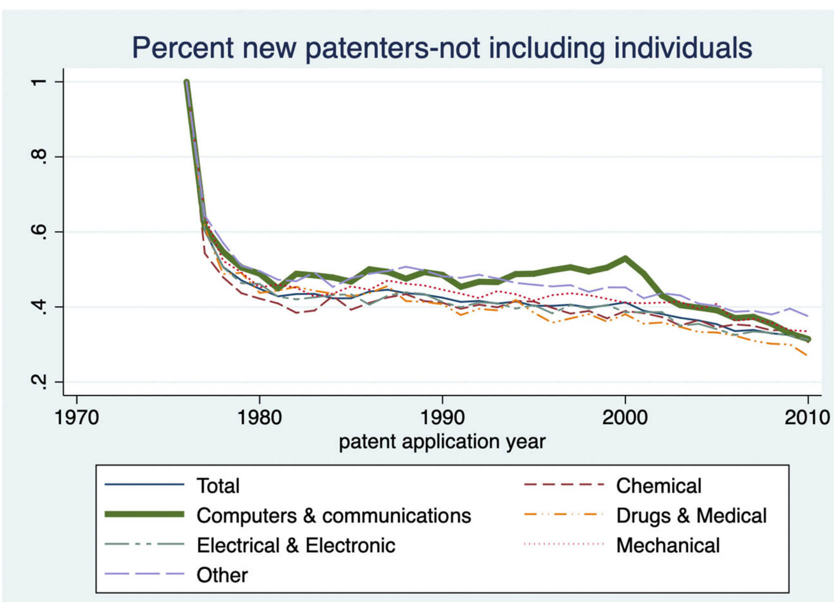
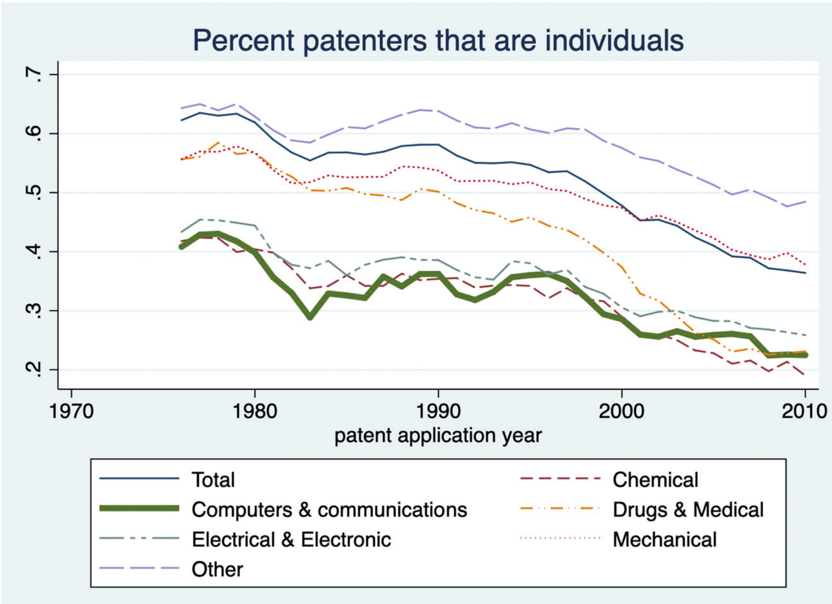


Figure 5b: New patenting firms over time



[3] See Hall and MacGarvie (2010) and Cockburn and MacGarvie (2009) for further details.

Figure 5c: Individual patenters over time



Increased geographic concentration of new IT patenters. Figure 6 shows that the geographic concentration of new IT patenters has grown over time. In other words, the increasing geographic concentration of patenting shown in Figure 4 is not mechanically a result of the increased firm-level concentration of patenting. New firms are also geographically concentrated. Figure 6a shows all first time patenters. Figure 6b shows firms only.

Figure 6a: Geographic concentration of first time patenters over time

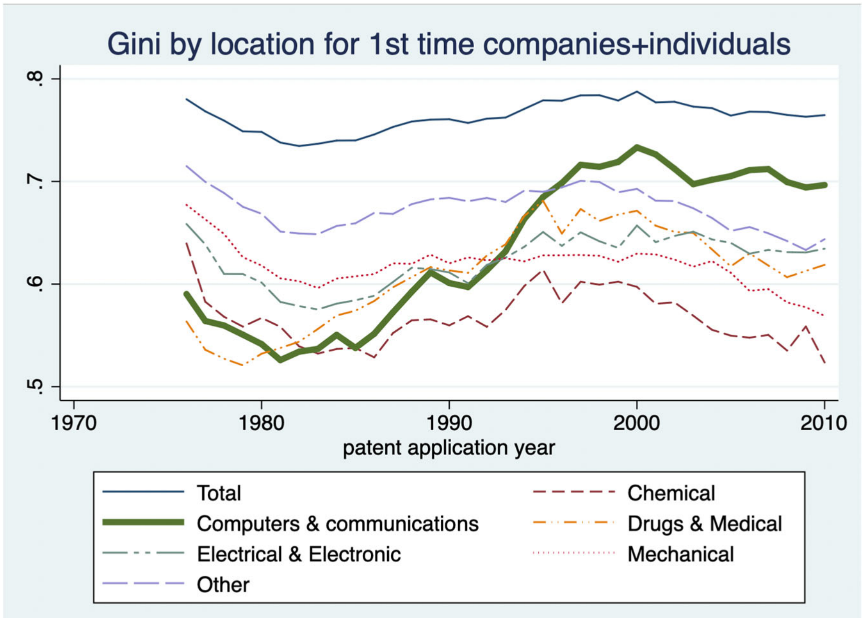
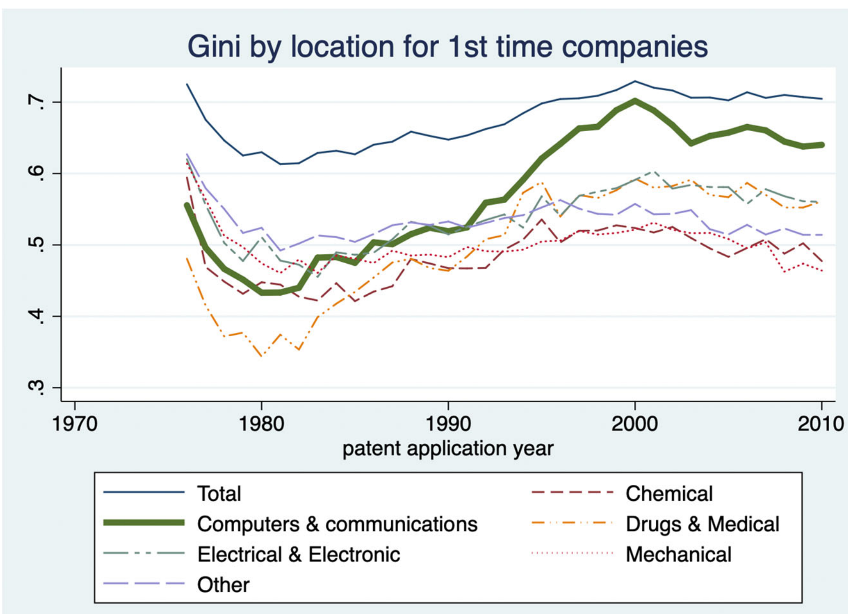


Figure 6b: Geographic concentration of first time firm patenters over time



Similar results across IT subcategories. Figure 7 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 7a shows firm 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 Gini throughout most of the sample, but this declines between 2000 and 2010. Figure 7b shows that the increases in Gini by location hold across all subcategories of IT.

Figure 7a: Firm-level concentration over time by IT subclass

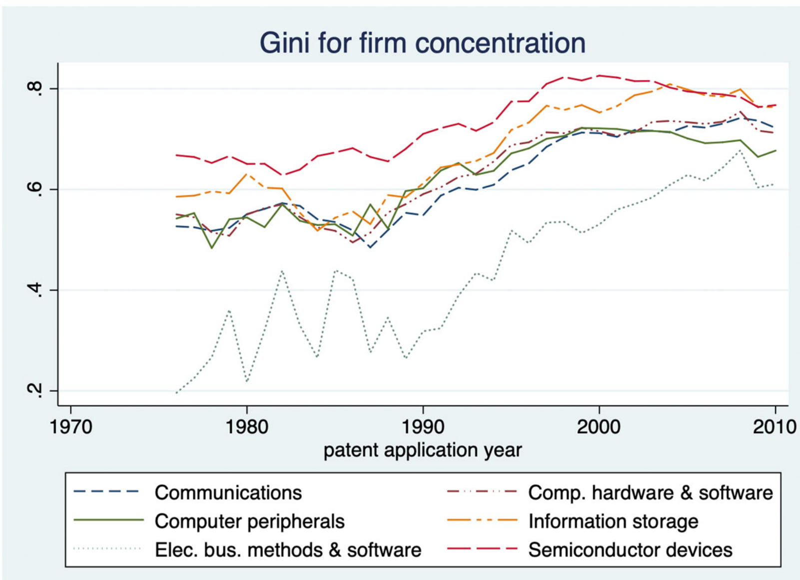


Figure 7b: Location-level concentration over time by IT subclass

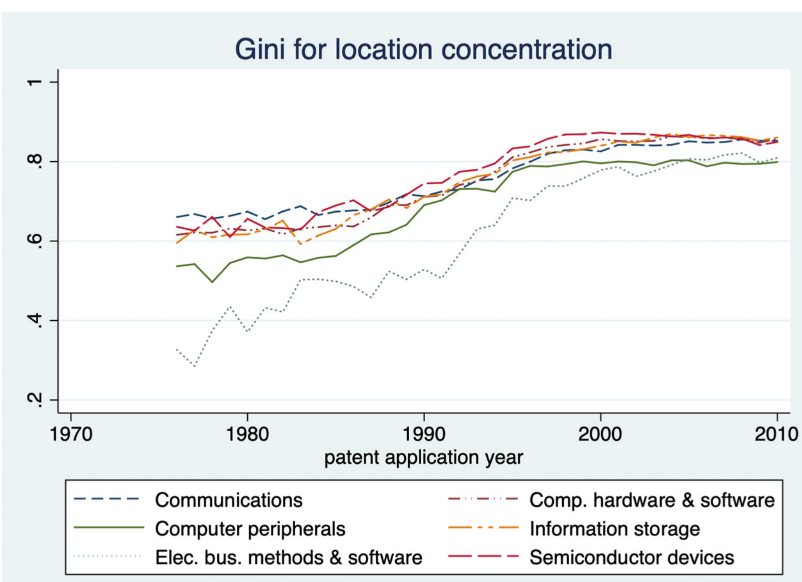
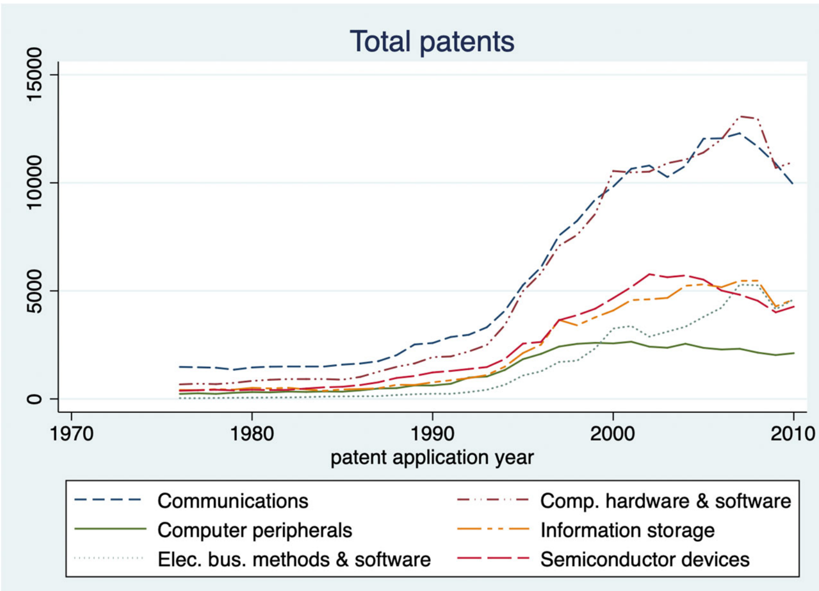


Figure 8 provides context, showing the trend in total patents over time for each subclass. It suggests that business methods & software grow from effectively zero in mid 1990s to comprise a meaningful share of all IT patents.

Figure 8: Total patents over time by IT subclass



Hypotheses on the rise of concentration

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

Why is firm-level concentration rising?

We identify ten possible (sometimes overlapping) reasons why 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 in a communication technology or indirectly as in online platforms, then this can lead to an increase in industry concentration (e.g., Katz and Shapiro 1985; Armstrong 2006). 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 there a concentration in firm-level IT patenting.

2) *Superstar effects in demand for IT*: Information technology has lowered the cost of searching for information (Shapiro and Varian 1998; Goldfarb and Tucker 2019). This 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 (Rosen 1981; Bar Isaac et al 2012).

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 are high fixed cost and low marginal cost. 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 each other in R&D, it requires an increasing amount of resources 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 between 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 IT using firms (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 not an easy strategy for a new entrant to invest in generating the intangible capital needed to compete. Intangible can therefore lead to firm-level concentration among IT using firms. These IT using 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) *Anti-competitive behavior*: The Stigler Report (Stigler Center 2019) emphasized 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 has become more lenient over time in the IT industry (e.g. Gutierrez 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 this time, the IT industry was relatively new. In the early stages of an industry, it is not unusual for a large number of competitors to enter and then for a few firms to dominate over time (Klepper and Graddy 1990; Klepper 2002). 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 has historically been weaker among some inventions based on IT, particularly those based on business methods and software. As we note above, strengthening of intellectual property protection in software was coincident with an increase of patenting in these categories. This increase in patenting may have made it more difficult for de novo start-ups to receive financing and enter into markets (Cockburn and MacGarvie 2009, 2011). Conversely, uncertainty about the strength of patents can lead to concerns about expropriation of intellectual property assets when start-ups 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 upon 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 a comprehensive emphasis on robustness. Instead, we have focused on identifying a puzzle that warrants further examination.

The above hypotheses are not mutually exclusive. Furthermore, many 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 anti-competitive behavior then it is welfare-reducing.

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 upon work that has highlighted the reasons for location level concentration more generally, and leave understanding for why the benefits of concentration might be different in IT for future work. We identify four possible reasons:

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 this 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 et al (2014) show that IT adoption is more effective in cities. Outside of IT, the increased importance of agglomeration economies between 1980 and 2010 is well-documented in the urban economics literature (Duranton

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

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 could drive our result and it might have little to do with innovation generally.

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 increasingly concentrated across a smaller number of locations. These patterns are found across different categories of IT, though there is some evidence that the patterns may be stronger in Electronic Business Methods and 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 into other inventions. There is rising concentration across firms both in IT and outside of 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 who have been affected by digital platforms (Stigler Center 2019). However, there is a long run trend in 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 within and across industries, the increasing concentration of innovation in IT, and IT's increasing using as an input in innovation may encourage the development of superstar cities documented elsewhere (Gyourko, Mayer, and Sinai 2013).

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 are available over a long period of 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, and so as a result our results must be viewed with some care. Further, our results end with patents applied for in 2010. As a result, our results miss recent developments that may arise as a result 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 are their implications, 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.

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.

References

Andreessen, Marc. "Why Software is Eating the World," The Wall Street Journal, Aug. 20, 2011.

Andrews, Dan, Chiara Criscuolo, and Peter N. Gal. 2019. "The Best Versus the Rest: Divergence Across Firms During the Global Productivity Slowdown." *Centre for Economic Performance.*

Aral, Sinan, Erik Brynjolfsson, and Lynn Wu. 2012. "Three-Way Complementarities: Performance Pay, Human Resource Analytics, and Information Technology." *Management Science* 58(5): 913-931.

Armstrong, Mark. 2006. “Competition in Tow-Sided Markets.” *The RAND Journal of Economics* 37(3): 668-691.

Arora, Ashish, Andrea Fosfuri, and Alfonso Gambardella. 2004. *Markets for Technology: The Economics of Innovation and Corporate Strategy.* Cambridge, MA: The MIT Press.

Arora, Ashish, Lee G. Branstetter, and Matej Drev. 2013. “Going Soft: How the Rise of Software-Based Innovation Led to the Decline of Japan’s IT Industry and the Resurgence of Silicon Valley.” *Review of Economics and Statistics* 95(3): 757-775.

Audretsch, David, and Maryann Feldman. 2004. “Knowledge Spillovers and the Geography of Innovation.” Chapter 61. In J. Vernon Henderson and Jacques-François Thisse, eds. *Handbook of Regional and Urban Economics*. Elsevier Volume 4: 2713-2739.

Autor, David, David Dorn, Lawrence F. Katz, Christina Patterson, and John Van Reenen. 2017. “Concentrating on the Fall of the Labor Share.” *American Economic Review* 107(5): 180-185.

Autor, David, David Dorn, Lawrence F. Katz, Christina Patterson, and John Van Reenen. 2020. “The Fall of the Labor Share and the Rise of Superstar Firms.” *Quarterly Journal of Economics, Forthcoming*.

Bar-Isaac, Heski, Guillermo Caruana, and Vicente Cuñat. 2012. “Search, Design, and Market Structure.” *The American Economic Review* 102(2): 1140-1160.

Berry, Steven, Martin Gaynor, and Fiona Scott Morton. 2019. “Do Increasing Markups Matter? Lessons from Empirical Industrial Organization.” *Journal of Economic Perspectives* 33(3): 44-68.

Bessen, James, and Robert M. Hunt. 2007. “An Empirical Look at Software Patents.” *Journal of Economics and Management Strategy* 16(1): 157-189.

Bloom, Nicholas, Charles I. Jones, John Van Reenen, and Michael Webb. 2020. “Are Ideas Getting Harder to Find?” *American Economic Review* 110(4): 1104-1144.

Branstetter, Lee G., Matej Drev, and Namho Kwon. 2019. “Get with the Program: Software-Driven Innovation in Traditional Manufacturing.” *Management Science* 65(2): 459-954.

Bresnahan, Timothy, and Pai-Ling Yin. 2017. "Adoption of New Information and Communications Technologies in the Workplace Today." *Innovation Policy and the Economy* 17: 95-124.

Bresnahan, Timothy, and Shane Greenstein. 1996. “Technical Progress and Co-Invention in Computing and in the Uses of Computers.” *Brookings Papers on Economic Activity: Microeconomoics* 27: 1-83.

Bresnahan, Timothy, and Shane Greenstein. 1999. "Technological Competition and the Structure of the Computer Industry." *Journal of Industrial Economics* 47(1): 1-40.

Bresnahan, Timothy F., Eric Brynjolfsson, and Lorin M. Hitt. 2002. "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence." *The Quarterly Journal of Economics* 117(1): 339-376.

Brynjolfsson, Erik, and Andrew McAfee. 2014. *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies.* New York, NY: W.W, Norton & Company.

Brynjolfsson, Erik, Andrew McAfee, Michael Sorell, and Feng Zhu. 2008. "Scale Without Mass: Business Process Replication and Industry Dynamics. Unit Research Paper no. 07-016, Harvard University.

Brynjolfsson, Erik, Daniel Rock, and Chad Syverson. 2019. "The Productivity J-Curve: How Intangibles Complement General Purpose Technologies." *American Economic Journal: Macroeconomics*. Forthcoming.

Carlino, Gerald A., and William Kerr. 2015. "Agglomeration and Innovation." In Gilles Duranton, J.V. Henderson, and William Strange, *Handbook of Regional and Urban Economics.* Volume 5, 349-404.

Cockburn, Iain, and Megan MacGarvie. 2009. "Patents, Thickets and the Financing of Early-Stage Firms: Evidence from the Software Industry", *Journal of Economics and Management Strategy*, 18(3), 729-773.

Cockburn, Iain, and Megan MacGarvie. 2011. "Entry and Patenting in the Software Industry", *Management Science*, 57(5), 915-933.

Cockburn, Iain M., Rebecca Henderson, and Scott Stern. "The Impact of Artificial Intelligence on Innovation: An Exploratory Analysis." Chap. 4 in *The Economics of Artificial Intelligence*, edited by Ajay K. Agrawal, Joshua Gans, and Avi Goldfarb. University of Chicago Press, 2019.

Cohen, Wesley M., Richard R. Nelson, and John P. Walsh. 2000. "Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)." NBER Working Paper no. 7552, Cambridge MA.

Corrado, Carol, Charles Hulten, and Daniel Sichel. 2009. "Intangible Capital and U.S. Economic Growth." *The Review of Income and Wealth* 55(3): 661-685.

De Loecker, Jan, Jan Eeckhout, and Gabriel Unger. 2020. "The Rise of Market Power and the Macroeconomic Implications." *The Quarterly Journal of Economics* 135(2): 561-644.

Dranove, David, Craig Garthwaite, and Christopher Ody. 2014. "Health Spending Slowdown is Mostly Due to Economic Factors, Not Structural Change in the Health Care Sector." *Health Affairs* 33(8): 1399-1406.

Duranton, Giles, and Diego Puga. 2004. "Micro-Foundations of Urban Agglomeration Economies." *Handbook of Regional and Urban Economics* 4: 2063-2117.

Eggertsson, Gauti B., Jacob A. Robbins, and Ella Getz Wold. 2018. "Kaldor and Piketty's Facts: The Rise of Monopoly Power in the United States." NBER Working Paper no. 24287, Cambridge, MA.

Einav, Liran, Chiara Farronato, and Jonathan Levin. 2016. "Peer-to-Peer Markets." *Annual Review of Economics* 8(1): 615-635.

Ellison, Glenn, and Edward Glaeser. 1997. "Geographic Concentration in U.S. Manufacturing Industries: A Dartboard Approach." *Journal of Political Economy* 105(5): 889-927.

Evans, Peter C. and Annabelle Gawer. 2016. The Rise of the Platform Enterprise: A Global Survey. The Center for Global Enterprise. Available at https://www.thecge.net/app/uploads/2016/01/PDF-WEB-Platform-Survey_01_12.pdf.

Feldman, Maryann P. and Dieter Kogler. 2010. "Stylized Facts in the Geography of Innovation", Chapter 8 in Bronwyn Hall and Nathan Rosenberg Eds, *Handbook of the Economics of Innovation*, 381-410, Elsevier.

Fernández-Delgado, Manuel, Eva Cernadas, Senén Barro, and Dinani Amorim. 2014. "Do We Need Hundreds of Classifiers to Solve Real World Classification Problems?" *Journal of Machine Learning Research* 15(90): 3133-3181.

Forman, Chris, Avi Goldfarb, and Shane Greenstein. 2012. "The Internet and Local Wages: A Puzzle." *The American Economic Review* 102(1): 556-575.

Forman, Chris, Avi Goldfarb, and Shane Greenstein. 2016. "Agglomeration of Invention in the Bay Area: Not Just ICT." *American Economic Review Papers & Proceedings* 106(5): 146-151.

Foroughi, Cirrus, and Ariel Dora Stern. 2018. "Digital Innovation with High Costs of Entry: Evidence from Software-Driven Medical Devices." Working Paper, Harvard Business School.

Furman, Jason, and Peter Orszag. 2015. "A Firm-Level Perspective on the Role of Rents in the Rise in Inequality." *Presentation at "A Just Society" Centennial Event in Honor of Joseph Stiglitz,* Columbia University.

Gans, Joshua S. and Scott Stern. 2003. "The Product Market and the Market for "Ideas": Commercialization Strategies for Technology Entrepreneurs." *Research Policy*, 32, 333-350.

Gans, Joshua S., David H. Hsu, and Scott Stern. 2002. "When Does Start-Up Innovation Spur the Gale of Creative Destruction?" *The RAND Journal of Economics* 33(4): 771-586.

Giorgi, Giovanni M. 2019. "Gini Coefficient." In *SAGE Research Methods Foundations,* edited by Paul Atkinson, Sara Delamont, Alexandru Cernat, Joseph W. Sakshaug, and Richard A. Williams.

Glaeser, Edward. 2012. *Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier, and Happier.* London, England: Penguin Books.

Glaeser, Edward L., Hedi D. Kallal, José A. Scheinkman, and Andrei Shleifer. 1992. "Growth in Cities." *Journal of Political Economy* 100(6): 1126-1152.

Goldfarb, Avi, and Catherine Tucker. 2019. "Digital Economics." *Journal of Economic Literature* 57(1): 3-43.

Graham, Stuart J.H., and David C. Mowrey. 2003. "Submarines in Software? Continuaitons in US software patenting in the 1980s and 1990s." *Economics of Innovation and New Technology* 13(5): 443-456.

Graham, Stuart J.H., Marco Ceccagnoli, Matthew J. Higgins, and Jeongsik Lee. 2010. "Productivity and the Role of Complementary Assets in Firms' Demand for Technology Innovations." *Industrial and Corporate Change* 19(3): 839-869.

Graham, Stuart J.H., Robert P. Merges, Pam Samuelson, and Ted M. Sichelman. 2009. "High Technology Entrepreneurs and the Patent System: Results of the 2008 Berkley Patent Survey." *Berkley Technology Law Journal* 24(4): 1275-1328.

Gutiérrez, Germán, and Thomas Philippon. 2017. "Declining Competition and Investment in the U.S." NBER Working Paper no. 23583, Cambridge, MA.

Gyourko, Joseph, Christopher Mayer, and Todd Sinai. 2013. "Superstar Cities." *American Economic Journal: Economic Policy*, 5(4): 167-99.

Hall, Bronwyn H., Adam B. Jaffe, and Manuel Trajtenberg. 2001. "The NBER Patent Citations Data File: Lessons, Insights and Methodological Tools." NBER Working Paper no. 8498, Cambridge, MA.

Hall, Bronwyn H., Adam Jaffe, and Manuel Trajtenberg. 2005. "Market Value and Patent Citations." *The RAND Journal of Economics* 36(1): 16-38.

Hall, Bronwyn H., and Megan MacGarvie. 2010. "The Private Value of Software Patents." *Research Policy* 39(7), 994-1009.

Hall, Bronwyn H., and Rosemarie Ham Ziedonis. 2001. "The Patent Paradox Revisited: An Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979-1995." *The RAND Journal of Economics* 32(1): 101-128.

Helsley, Robert W., and William C. Strange. 2014. "Coagglomeration, Clusters, and the Scale and Composition of Cities." *Journal of Political Economy* 122(5): 1064-1093.

Hendershott, Terrence, and Jie Zhang. 2006. "A Model of Direct and Intermediated Sales." *Journal of Economics and Management Strategy* 15(2): 279-316.

Henderson, J. Vernon, Ari Kuncoro, and Matthew Turner. 1995. "Industrial Development in Cities." *Journal of Political Economy* 103(5): 1067-1090.

Huang, Peng, Marco Ceccagnoli, Chris Forman, and D.J. Wu. 2013. "Appropriability Mechanisms and the Platform Partnership Decision: Evidence from Enterprise Software." *Management Science* 59(1): 102-121.

Jin, Wang, and Kristina McElheran. 2018. "Economies Before Scale: Survival and Performance of Young Plants in the Age of Cloud Computing." Working paper, Rotman School of Management.

Jones, Benjamin F. 2009. "The Burden of Knowledge and the 'Death of the Renaissance Man': Is Innovation Getting Harder?" *The Review of Economic Studies* 76(1): 283-317.

Jorgenson, Dale W., Mun S. Ho, and Kevin Stiroh. 2005. *Productivity, Volume 3: Information Technology and the American Growth Resurgence, vol 3.* Cambridge, MA: The MIT Press.

Jullien, Bruno, and Alessandro Pavan. 2019. "Information Management and Pricing in Platform Markets." *The Review of Economic Studies* 86(4):1666-1703.

Katz, Michael L., and Carl Shapiro. 1985. "Network Externalities, Competition, and Compatibility." *The American Economic Review* 75(3): 424-440.

Klepper, Steven. 2002. "Firm Survival and the Evolution of Oligopoly." *The RAND Journal of Economics* 33(1): 37-61.

Klepper, Steven, and Elizabeth Graddy. 1990. "The Evolution of New Industries and the Determinants of Market Structure." *The RAND Journal of Economics* 21(1): 27-44.

Kogan, Leonid, Dimitris Papanikolaou, Amit Seru, and Noah Stoffman. 2017. "Technological Innovation, Resource Allocation, and Growth." *The Quarterly Journal of Economics* 132(2): 665-712.

McAfee Andrew, and Erik Brynjolfsson. "Investing in the IT That Makes a Competitive Difference." *Harvard Business Review*, July-August 2008.

Merriam-Webster. 2020. https://www.merriam-webster.com/

Moretti, Enrico. 2019. "The Effect of High-Tech Clusters on the Productivity of Top Inventors." NBER Working Paper no. 26270, Cambridge, MA.

Picard, Robert. 2015. GEOINPOLY: Stata Module to Match Geographic Locations to Shapefile Polygons." Statistical Software Components, Boston College Department of Economics.

Rosen, Sherwin. 1981. "The Economics of Superstars." *The American Economic Review* 71(5): 845-858.

Rosenthal, Stuart, and William Strange. 2004. "Evidence on the Nature and Sources of Agglomeration Economies." Chapter 49. In J. Vernon Henderson and Jacques-François Thisse, eds. *Handbook of Regional and Urban Economics*. Elsevier Volume 4, p. 2119-2171.

Shapiro, Carl, and Hal R. Varian. 1998. *Information Rules: A Strategic Guide to the Network Economy*. Cambridge, MA: Harvard Business Press.

Statista. 2019. The 100 largest companies in the world by market value in 2019. Available at https://www.statista.com/statistics/263264/top-companies-in-the-world-by-market-value/.

Stigler Center for the Study of the Economy and the State. 2019. "Stigler Committee on Digital Platforms: Report." Chicago: Chicago Booth.

Stoffman, Noah, Michael Woeppel, and M. Deniz Yavuz. 2019. "Small Innovators: No Risk, No Return." Kelley School of Business Research Paper no. 19-5, Bloomington, IN.

Sutton, Stephen. 1998. "Predicting and Explaining Intentions and Behavior: How Well Are We Doing?" *Journal of Applied Social Psychology* 28(15): 1317-1338.

Syverson, Chad. 2017. "Challenges to Mismeasurement Explanations for the US Productivity Slowdown." *Journal of Economic Perspectives* 31(2): 165-186.

Tambe, Prasanna, and Lorin M. Hitt. 2012. "Now IT's Personal: Offshoring and the Shifting Skill Composition of the U.S. Information Technology Workforce." *Management Science* 58(4): 678-695.

Tambe, Prasanna, Lorin M. Hitt, Daniel Rock, and Erik Brynjolfsson. 2019. "IT, AI and the Growth of Intangible Capital." Working paper, Wharton.

The Economist. 2018. "How to Tame the Tech Titans." Available at https://www.economist.com/leaders/2018/01/18/how-to-tame-the-tech-titans.

Valleti, Tommaso M., and Hans Zenger. 2019. "Increasing Market Power and Merger Control." *Competition Law & Policy Debate* 5(1): 26-35.