Technological Leadership (de)Concentration: Causes in Information and Communication Technology Equipment

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Abstract

Using patent data from 1976 to 2010 as indicators of inventive activity, we determine the concentration level of where inventive ideas originate and then examine how and why those concentrations change over time. The analysis finds pervasive deconcentration in every area related to the Information and Communication Technology equipment market. We find that booms and busts play an important role in deconcentration trends. In comparison, new entry explains surprisingly little, and merger and acquisition activity does not revert the trend.

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I. Introduction

Over the past four decades, the market structure for the Information and Communications Technology (ICT) equipment industry has experienced immense changes. In the 1970s, most innovation occurred in established firms, in large laboratories such as Bell Labs and IBM Labs (Rosenbloom and Spencer 1996), but decades ago these large labs began losing their dominance to widespread, decentralized, and small-scale innovators. This trend has many names in many analyses. Here, though, we use the label *divided technical leadership*, or DTL for short, a framework established by Bresnahan and Greenstein (1999), who argue that DTL contributes to high rates of firm entry. Key to shaping a market environment that nurtures open innovation (Chesbrough 2003), DTL supports open and proprietary platforms (Gawer 2010; Greenstein 2010) and encourages "innovation from the edges" (Greenstein 2015). Such a market structure, in which a dispersed set of market participants produces a range of new innovative prototypes for potential acquisition, allows for externalization of research and development (R&D), where large firms use acquisitions of smaller firms for many of their innovative activities (Gans, Hsu, and Stern 2002). Cisco, IBM, and Apple, for example, participate in such activities, and each of them have made more than one hundred acquisitions over the last two decades.

The causes behind the rise of DTL has not been examined partly because of the slow pace of change in market structure. Large-scale DTL did not arise instantaneously; rather, it gradually emerged in different parts of ICT markets, and only over time spans of several decades has it become visible and amenable to statistical analysis. Additional challenges to operationalizing measurement also slowed progress. Addressing these challenges, this study offers the first statistical information describing DTL, and the first econometric analysis of some of the causes behind DTL. For our analysis of DTL, we focus on the deconcentration of invention, and the research goals are both descriptive and causal, and measurement challenges determine the lengths to which we can pursue both goals.

Our study supports the prevailing view about historical trends in DTL in that we find a trend in deconcentration in the cumulative ownership of active patents. Related results were first reported in our previous study, Ozcan and Greenstein (2013), where we concentrated on the *flow of new ideas*.[1] In this study, we concentrate on the *stock of ideas* that firms own and use. A firm acquires ownership of many inventions by accumulating ownership of patents over their lifetime, which we coin the *patent stock.*[2] And our study is the first to aggregate all the data and identify the technology classes at the owner level, and, for a number of reasons discussed below, it is the most appropriate unit of analysis for measuring the holding of DTL. Our goals are to determine the level of the concentration of ownership and holdings of inventive ideas within each technology class and then examine how and why those concentrations change over time.

To realize our research goals, our study examines the concentration of granted patents in ICT equipment in the period from 1976 to 2010, which accounts for roughly 14% of all U.S. patents. The study utilizes a dataset constructed from XML (Extensible Markup Language) and text files of patents granted by the United States Patent and Trademark Office (USPTO) between 1976 and 2010. In comparison to the National Bureau of Economic Research (NBER) patent data files, which are the standard data source for many studies on patents,[3] our data has the advantage of including four additional years (i.e., 2006–2010). The novel length of time covered is essential,

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[1] There we note that the top twenty-five firms' responsibility for new patents dropped from 72% in 1976 to 55% in 2010. And when we restricted the sample to high-quality patents the numbers changed even more dramatically—from 86% to 62%.

[2] We will go into further detail about patent stock subsequently. In addition, although, we focus on the stock of ideas, our qualitative results also hold in the flow of ideas, the results of which we provide in Appendix B.

[3] For details on the NBER patent data files, see Hall, Jaffe, and Trajtenberg (2001).

because the economic forces studied are manifested in slow changes, if at all, and at varying paces in different technical areas.

Most important, the data allows us to examine two novel topics: First, because the data contains standardized patent assignee names, we can link it to other information about mergers and acquisitions (M&A) activity. Second, this length of time enables us to take into account booms and busts as a factor in the restructuring of ICT equipment market activity—specifically, the PC (personal computer) boom of the 1980s and the slow period during early 1990s, as well as the dot-com boom, which is coincident with the acceleration in patenting in the late 1990s, and its bust, which occurs in the early 2000s.

Following frameworks developed in prior literature (Arora and Gambardella 2001; Gans, Hsu and Stern 2002), we divide the industry into an "upstream path" that supplies invention and a "downstream path" that supplies technology products, where the downstream path employs inventions from the upstream path. We interpret patents as indicators of invention at the upstream level, and we measure the concentration of invention based on the assignment of the patent.

Because invention occurs as result of both upstream and downstream paths for innovation, we address novel questions to both aspects to determine how and why changes occurred to the concentration of invention. With regards to the upstream path, we ask the following: Does statistical evidence of long-term change show a deconcentration in the sources of inventive ideas, as held by conventional models of DTL?

We then characterize the concentration of inventions in the ICT equipment industry in a given year and find trends consistent with the increasing importance of DTL. When we turn to the downstream path we ask, do changes in the demand for ideas from 1976 to 2010 affect the deconcentration of invention in the upstream path? If so, in which direction does it have an impact? We then test hypotheses about these downstream path factors.

We first perform a descriptive exercise and verify that deconcentration has, in fact, occurred. Then we ask two overarching questions: (1) What factors caused this deconcentration with regards to the upstream and downstream paths for inventive ideas? (2) How did these factors drive change in the ICT equipment market? This part of the study uses variance between different technology segments within ICT equipment to identify determinants of changes in concentration. The statistical exercise tests several hypotheses focused on whether location, economies of scope, product market leadership, or entry by domestic and foreign firms influence concentration in invention.

We first look at the downstream side, specifically, the M&A market: Does the emergence of an active merger market cause this deconcentration? Rather than own all the inputs into creating ideas that lead to patents, many large firms increasingly let others focus on that activity and make the purchase after the patent is granted.[4] Using extensive data-matching, we perform the first census of such merger activity for ICT equipment and find that M&A activity results in the transfer of approximately 11% of the entire patent stock and 12% of the high-quality patent stock in the ICT equipment industry. Although the intensity of patent transfer through M&A is associated with a slight increase in concentration for high-quality patents, the size of this transfer is not enough to revert the composition of ownership to its pre-deconcentration levels in any segment. Moreover, in the regression analysis, merger activity and intensity, which proxies for downstream demand for externalized invention, cannot explain variance in concentration

[4] See Ahuja and Katila (2001) and Cassiman and Valentini (2016), for open innovation, and Ozcan (2016) for transfer of invention through M&A activity.

between segments. We conclude that the trend toward deconcentration has not been due to, or entirely reversed by, firm strategies to externalize R&D activity.

Next we examine upstream causes of deconcentration. We examine economies of scope, reduced costs of entering new technologies, decline in leading firms, or the location of the invention as possible causes for deconcentration. One hypothesis stresses that large firms may utilize economies of scope by entering other technology areas, which may appear as increased or decreased concentration, depending on the size of the entry.[5] We use such lateral entry as a proxy for economies of scope and find evidence that ownership concentration *increases* with lateral entry—in other words, economies of scope are not a cause of deconcentration. Next, we find mixed evidence that *de novo* firm entry causes the deconcentration. There also is little evidence that non-U.S. firm entry caused the change, another common hypothesis founded on the growth in imports and exports in the U.S. economy over this period.[6] Rather, we find that established changes in concentration may come from two distinct areas of the ownership distribution: (1) declines in the leading, large firms and (2) an increase of invention in the small, "tail" firms within the U.S. These entry results are consistent with the growth of small firms as a source of ideas, perhaps as part of redistribution from other domestic large firms.

We further explore a popular hypothesis about large firms: Namely, does the decline in the importance of the very largest firms merely reflect a decline in their importance in downstream

[5] For economies of scope in technology see e.g. Chen, Williams, and Agarwal (2012), Leiponen and Helfat (2010), and Miller (2006).

[6] As with the rest of the literature, we are somewhat cautious in our interpretation of foreign firms. A patent owned by Sony, for example, will appear as a U.S. patent due to the location of its U.S.-based subsidiary. As with the prior literature (e.g., Hall 2005), we focus on changes due to U.S. patents with U.S. assignees and non-U.S. assignees, and examine whether the surge in patenting with Asian and European assignees accounts for change.

markets?[7] The preponderance of evidence rejects the hypothesis that long-term trends in deconcentration can be attributed solely to the presence of IBM or Motorola, or to the divestiture of AT&T. Hence, we can reject the most sweeping version of the hypothesis that points to one antitrust case, one company's strategic error, or the break-up of one large, leading innovator of yesteryear as the cause for deconcentration.

Finally, our more up-to-date data on patents allows us to answer open questions posed by Hall (2005), such as "What happened during the 1990s? Did the positive premium for entry with patents continue during the rapid growth of the computing and electronics sector in the late 1990s? Has the growth in patenting continued to be due almost entirely to U.S. firms in computing and electronics?" And, our analysis provides evidence of the increased competitive conditions in the ideas market. This increased competition may be indicative of higher incentives to innovate. However, our results cannot distinguish between a model of monotonic increase in innovation due to more competition, or merely a movement on the upward part of the "inverted U" relationship hypothesized by Aghion *et al.* (2005), because the results are consistent with both theories.

The rest of the paper is organized as follows: In Part II, we discuss our study's relation to prior research. In Part III, we provide a historical overview of the industry. We then develop the framework for our study in Part IV. We present our Data in Part V; and in Part VI, discuss concentration and other measures. The next section, Part VII, we examine deconcentration and patent stock share. And, in Part VIII, we examine the role of M&As. We next look at the model of the composition of patent stock in Part IX. Finally, in Part X, we present our conclusion.

[7] See Miller (2006) for the relation between technology and product markets of firms.

II. Relation to Prior Research

Our study connects to previous research in two broad ways. First, it relates to the literature on DTL, as noted, and, more broadly, to an analysis of the causes of market leadership and incentives in inventive activities. Following this literature,[8] we generally distinguish between product market leadership and technological leadership and focus on the latter. We follow the literature that hypothesizes that the dispersion of capabilities over frontier technology shapes firm behavior.

Second, our discussion of the impact of M&A activity on technological leadership relates to literature on R&D incentives in the shadow of M&As and to literature on start-up commercialization. Notably, though, our study differs from prior literature because of our focus on understanding the causes behind changes in technical leadership in more recent decades. Our study also is the first to investigate the extent of, and causes behind, invention deconcentration in the ICT equipment industry, and the potentially countervailing M&A mechanism within the framework of boom and bust economies. In addition, most of the prior literature on the interaction of M&A activity and innovation comes from analyses of public firms. We contribute to the literature by analyzing private firms, which fills a substantial gap. For example, Asker, Farre-Mensa, and Ljungqvist (2012) estimate that private U.S. firms account for 67.1% of private sector employment, 57.6% of sales, and 20.6% of aggregate pre-tax profits. As a result, analyses of M&A activity that filter out the deals of private firms yield biased results.[9] We expect this bias to be

[8] Greenstein (2010) and (2015) review the literature on computing and commercial Internet, in particular.

[9] See Netter, Stegemoller, and Wintoki (2011) for a detailed discussion of potential biases of M&A filtering criteria.

exacerbated through acquisition of startup firms, because startup firms are likely to be underrepresented in deals of only public firms and we explore that data.[10]

We also follow prior research that considers industry and firm effects in a unified framework by examining together both resource-based streams and industrial organization streams.[11] Yet, we differ from Skilton and Bernardes (2015) in that we distinguish between technology markets and product markets and stress competition and entry into the former instead of the latter.

In addition, our study relates to the start-up commercialization framework of Arora, Fosfuri, and Gambardella (2004), and Gans, Hsu, and Stern (2002). Their framework posits that a startup innovator with a commercial, successfully developed technology faces a choice between competing with incumbent firms in the market and cooperating by selling or licensing the technology to those firms. Our study proceeds from the same premise, and we test for the role of all acquisitions of patents.

Finally, we also build on prior research into the propensity to patent, which has not examined the sources of deconcentration. Kortum and Lerner's (1999) study explains that the increase in U.S. patenting activity was due to both an increase in laws for U.S. innovation and changes in the management of R&D. Kim and Marschke (2004) conclude that firms' rate of patenting, (i.e. the ratio of ideas that a firm decides to patent) increased patenting activity instead of other potential sources, such as increase in the technological opportunities available to firms. ,

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[10] The precise fraction of private/public in ICT equipment is hard to know. While the presence of many startups and small firms would lead us to expect many private firms, many parts of the electronic equipment sector partially overlaps with manufacturing, where large public firms dominate. So it is hard to know precisely how our sample compares with these overall trends.

[11] See e.g. Mauri and Michaels (1998), Hashai (2015), and Misangyi *et al.* (2006)

Jaffe and Lerner (2004) place emphasis on changes in the legal rules for patent system. Hall and Zeidonis (2001) explain the rise of patenting among semiconductor firms as a part of the rise in design specialists, and as part of a "portfolio race." Hall (2005) finds that growth occurred in complex product industries such as telecommunications and concludes that this increase also spilled over to those firms' patenting behavior in other industries. Although we borrow themes from studies such as these, we will have little to say on *why* propensity to patent grew. Much of the growth in patenting will become subsumed under time and segment trends, and we focus on explaining why concentration varies over time and across segments.

III. Historical Overview

IIIa. ICT Equipment Industry Concentration

It would take several books to describe the changes in market structure for ICT equipment during the 1970s, but it is nevertheless important to note a few important details about what is known about the concentration of origins of inventive ideas. This will guide our framework for the statistical exercise.

Prior to the 1980s, the ICT equipment industry was split between two market segments—one oriented toward computing and the other toward communications—and both were highly concentrated in final goods markets. We now briefly discuss two of the dominant firms during those decades and how their market share decreased over time—IBM and its short-lived dominance of the computing market and AT&T with its monopoly of the communications segment.

At the end of the 1970s, IBM dominated the computing segment. Additionally, in 1981, IBM introduced the PC, so it also dominated the PC system market for a short time—in 1984, its PC systems division was the third-largest computer company on the planet, behind Digital

Equipment Corporation and the rest of IBM itself. Subsequently, during what is often termed *the 1980s PC boom*, a wide range of firms entered into printers, software, component production, local area networks (LANSs), and more. And after the mid-1980s, IBM consistently lost market shares in PCs and related markets. Simultaneously, on the upstream side of invention, venture capital activity in the ICT equipment market also saw a dramatic increase in firm entry. Then in the 1990s, despite Microsoft and Intel beginning to assert control over an increasing fraction of valuable components within the PC market, a large number of other firms played roles in many of its segments.

In the communications segment, before the 1980s, AT&T was the dominant provider of networking equipment mostly because of its regulated monopoly position in the telecommunication carrier services; and AT&T's equipment subsidiary, Western Electric, supplied approximately 90% of AT&T's equipment purchases. The voice segment was based on circuit-switching technology and provided the infrastructure for local and long-distance telephone companies. Furthermore, AT&T fought regulations that permitted equipment from non-AT&T suppliers to be attached to its network. This restricted entry into the telecommunications equipment markets and reinforced AT&T's dominant position.

Because AT&T eventually lost most of those regulatory fights, change occurred, but it did so slowly. In 1968, AT&T lost an antitrust suit against Carterfone Company and was forced to permit private interconnection equipment on the AT&T network. Then, in 1975, the Federal Communications Commission (FCC) extended the Carterfone decision to all private subscriber equipment registered to and certified by the FCC. Both the 1968 and 1975 decisions removed barriers to entry into the telecommunications equipment industry. In 1982, the telecommunications market structure changed further when the 1974 U.S. Department of Justice antitrust suit against

AT&T was finally settled, with AT&T dividing itself into one long-distance telephone provider and seven independent, regional holding companies. That eventually altered equipment purchasing decisions, and the telephone markets underwent considerable changes in the early to mid-1990s.[12]

The networking and Internet revolution of the 1990s blurred the distinction between different segments of ICT equipment industry (Lee 2007). Previously independent product market segments increasingly became substitutes or complements in demand. On the computing side, systems of PCs and workstations were initially hooked together with a LAN. Over time, client-server systems within large enterprises and across ownership boundaries were established. Novell, 3Com, Oracle, and Cisco were among the firms with dominant positions in this era.[13] With widespread Internet use, the scope of ambitions became larger still, touching on virtually every economic activity. This period was marked by large economic changes. It became labeled *the dot-com boom* in recognition of the many startups that ended with the top-level domain name "com."[14]

At the beginning of the millennium, many layers of the industry underwent upheaval. Some of this was associated with the "Telecom Meltdown." Some of it was due to the dot-com *bust*. Eventually the equipment market stabilized, leaving Cisco in the dominant position in enterprise computing and data communications. Other firms that grew spectacularly during the 1990s, such as JDS Uniphase, Corning, Lucent, Nortel, and 3Com, did not fare as well.

[12] See, e.g., Crandall and Waverman (1995) for a detailed discussion.

[13] See, e.g., Bresnahan and Greenstein (1999).

[14] For a review of the extensive literature on trends and causes, see Greenstein (2010, 2015).

This brief review shows two distinct periods of booms and busts that we will explore in our statistical work. The next section provides a brief overview of our framework. It fixes a few key ideas and provides a roadmap for later developments.

IV. Framework

The prevalence of DTL increases when the frequency of one firm having a monopoly over an idea decreases.[15] Such monopolies are less likely to arise when many technical substitutes can emerge. And those substitutes are more likely to emerge when many potential inventors generate similar ideas and when entry into production of ideas is less costly.

We considered a range of alternative ways to measure settings in which many potential inventors generate similar ideas. As in our previous study, our main variable is the patent ownership concentration in a technology class per year. Because in many of the early years, the top twenty-five firms owned 100% of the patents, we settle on a top-twenty-five concentration ratio over the ownership of inventive ideas, which we label as *C25*, in a technological class, indexed as *j*. Illustrating the concept, a technological class *j* is said to be more concentrated if the largest twenty-five firms own 80% of the inventive ideas, instead of, say, 50% of the ideas in that technology class.

As previously mentioned, the literature discusses relates measures of concentration for a sector, which are bracketed by two concepts, one associated to the *flow of new ideas*, another associated to the *stock of ideas* that firms own and use. A firm acquires ownership of many inventions by accumulating ownership of patents over its lifetime, which we label the firm's *patent stock.* In this paper we focus on the patent stock of ideas.

[15] See Bresnahan and Greenstein (1999).

Based on the set of active patents in a given year, we calculate the patent stock by discounting the patents from prior years and by using the declining balance formula.[16] More specifically, we calculate the cumulative patent stock of firm *i* in period *t* by the following formula:

$$Stock_{i,t} = Flow_{i,t} + (1 - \delta) * Stock_{i,t-1},$$

where we use the depreciation rate, δ, of 15%.[17] This depreciation accounts for two known factors, namely, (1) the obsolescence of patents over time as the technology becomes older and irrelevant, and (2) the shorter remaining active time of older patents. Both of these imply a lower value for the patents. The above definition also can be modified for the stock of only high-quality ideas.[18] Also, and crucially for our purposes, focusing on depreciated stocks also enables analysis of the role of acquisitions, which adds combines stocks of patents through mergers of two firms.

Our first question concerns the changes in the concentration of ownership over time. Is it decreasing over time? We focused on the question for each *i*, namely,

$$(C25_{stock})_{i,t} - (C25_{stock})_{i,t-1} < 0\,.$$

Generally, we find that a wide range of technology classes did become more deconcentrated. This motivates our second question concerning the causes of deconcentration. We identify the causes of the variance in changes of concentration between different technology classes. That is, we posit the following:

$$(C25_{stock})_{i,t} - (C25_{stock})_{i,t-1} = f(Upstream\ in\ i, Downstream\ in\ i).$$

[16] For the purposes of calculating the patent stock, we consider a patent active for twenty years, starting with the patent filing year, or for seventeen years, starting from the patent grant year, whichever comes later.

[17] The returns to patents are estimated to decline by 10% to 20% per year (Schankerman and Pakes 1986). In calculating the patent stock, use of the declining balance formula with 15% depreciation rate is prevalent in the literature (e.g., Griliches 1989; Hall, Jaffe, and Trajtenberg 2005; and Hall and MacGarvie 2010).

[18] In this study we provide results for patents that receive the bulk of citations, which are presumed to be of higher quality. We define *high quality* as the top quartile within each technology class-year group cells, in terms of citations received. For details, see Appendix A3.

There are various theories for the changes in concentration. We divide these theories into two distinct groups—each group correlates with either the upstream path or the downstream path of the technology. Figure 1 provides the map of these paths, along with their counterparts that we define in Section V. Important upstream factors include the following:

- The location of inventive activity
- Changes in firm entry in which we incorporate variables regarding
    a. Changes in entry costs for small or foreign firms
    b. Economies of scope across technology sectors
    c. Distinctions between lateral entry and new entry
    d. Growth in the number of firms active in a technology class
    e. Growth in the number of patents
- Product market leadership and the decline of dominant firms

Important downstream factors include the following:

- The increasing use of M&A by leading firms to obtain invention from external sources
- The cost of diffusing ideas
- Increasing user acceptance of technical products from unbranded firms
- The increasing use of open standards that permits customers to buy interoperable products from more than one supplier

Many of these theories are challenging to measure in practice because they operate over long time spans and through multiple pathways. Measuring the operation of these theories requires observations that correlate changes in concentration with measurement of upstream and downstream factor(s). Econometric analysis can identify only the cause of observed short run factors, while the time dummies potentially can describe macro trends. To illustrate, we foreshadow our estimation strategy. Estimation takes the following form:

$$(C25_{stock})_{jt} = \beta_0 * X_{jt} + \gamma_j + \theta_t + \varepsilon_{jt},$$

where j is the technology class indicator and t is the time indicator, X_{jt} represent upstream and downstream factors for class j in time t, and γ_j and θ_t are, respectively, class and time dummies (for thirty technology classes and twenty two time periods – see below). Figure 1 illustrates the challenge. It is necessary to include γ_j because each technology class contains rather different average levels of concentration, and it is necessary to include θ_t due to the presence of macroeconomic factors or changing legal conditions, which simultaneously influences all the technology classes. Many unmeasured trends shape the estimates for γ_j and θ_t. However, as we argue below, the estimate themselves suggest a specific interpretation of timing consistent with the effect of investment booms.

All this implies that estimates for β_0 are identified off of variance within class that departs from averages in a class and from time trends. The presence of a full span of dummies simultaneously strengthens and limits identification of β_0 to identify only short run factors. This will measure only the short run manifestations of the long run process. We now elaborate on this conceptual framework before providing specific measures.

Many long run downstream factors will be absorbed into time trends, such as the general changes in user acceptance of technical products from unbranded firms, and the increasing use of open standards. In spite of that limitation, we can measure short run factors correlated with changes in the M&A market and the cost of diffusing new ideas. Rather than themselves own and create all the inputs that lead to patents, many large firms increasingly let other firms focus on creating the invention and then purchase the patent or the other firm after the patent has been granted.[19] We construct a measure of *Merger Intensity* to account for this phenomenon. In this setting, a higher *Merger Intensity* implies a lower transaction cost of absorbing ideas from small firms. This will be measured by the acquisition of patents through the acquisition of other patent assignees.

Next consider measurement of a number of upstream factors. The location of the inventive activity constitutes an upstream-side factor in deconcentration. Metropolitan areas may create a lower concentration of patent origins, because they nurture small firms by providing smaller firms with both access to a highly-skilled work force and an ecosystem of complementary services within which to thrive.[20] Such an ecosystem may result in metropolitan areas substituting for large, established firms, hence enabling outsourcing of invention. Alternatively, metropolitan areas may create a high geographic concentration of patent origins, because they may create an ecosystem in which there are high entry costs or fewer sources for diffusing the underlying know-how, which then leads to a higher concentration of economic activity in a smaller set of urban areas. The former would result in a decrease in concentration of inventive ownership, while the latter would result in an increase in the concentration of inventive ownership. We consider this an empirical question.

Firm entry into innovative activities is another potential upstream factor (e.g., Hall 2005; Kortum and Lerner 1999), and we measure several short run behaviors correlated with firm entry. Firm entry captures the transaction costs of entry into the market for ideas, with lower costs implying higher entry. When we focus on only foreign entry, we then capture the transaction costs of entry by non-U.S. firms. In addition, we consider economies of scope, where firms may also

[19] See Ahuja and Katila (2001) and Cassiman and Valentini (2016), for open innovation, and Ozcan (2016) for transfer of invention through M&A activity.

[20] See Chang and Wu (2014) for a discussion of the role of agglomeration on entrant costs.

be active in one ICT equipment class and later move to a new ICT equipment class, as *lateral entrants*. A higher lateral entry level implies higher economies of scope across different technology classes. And, when examining these factors, we also consider changes in the number of firms active in a technology class, as well as changes in the number of patents generated.

The final upstream-side factor we consider is product market leadership. Product markets constitute the downstream for innovation markets, but the leadership of product market affects the upstream side. Fragmented product market leadership is more conducive to the commercialization of the upstream invention (Gambardella and Giarratana 2013). We theorize that a more concentrated product market, with only a few firms leading, would result in fewer firms entering into upstream inventive activity due to their lower probability of success in commercialization. This theory is further strengthened by the conventional wisdom that the divestiture of AT&T caused the deconcentration in patent ownership. We use the presence of a large firm as a proxy product market leadership. Once again, general deterioration in the leaders of a firm will indirectly affect all market participants, so it will be measured by the time trends, which means we measure only short run influences of product market leadership.

V. Data

The use of patent data as a proxy for inventive activity dates back to Schmookler (1951) and Griliches (1990); and an extensive literature has subsequently developed,[21] which we follow here. Patents granted in the ICT equipment industry proxy for the origins of innovative activity.

The NBER patent data files has been the standard source for patent data, but here we use raw USPTO files to construct updated patent data files and enable linkage between the patent data

[21] See also Nagaoka, Motohashi, and Goto (2010).

and the M&A data. In Appendices A and B, we describe the construction of patent data from 1976 to 2010 and the data linking procedure, respectively. We identify the ICT equipment industry in the patent data by extracting forty-four patent technology classes from the USPTO patent data: fourteen technology classes identified as communications by Hall, Jaffe, and Trajtenberg (2001); twenty-two technology classes in the seven-hundred ranges; and eight classes identified as relevant to telecommunications in the USPTO communications report. We then drop fourteen classes due to sparse patenting activity.[22] Table 1 contains lists of all considered classes. We encounter truncation created by the application-grant lag in the patent system. Accordingly, we restrict our sample to patents applied for between 1976 and 2007.

The final dataset has 550,884 patents with primary technology classes in the thirty ICT equipment classes, assigned to 38,359 unique assignees. The patent literature firmly establishes that patent values are highly skewed, with studies noting that the most valuable 10% of patents account for as much as 80% of the total value of patents. Below we provide results for patents that receive the bulk of citations, which are presumed to be of higher quality. We also examine the entire sample of patents and the top decile of patents, without any large change in inference. In Appendix C, we report these results. Appendix A5 provides summary statistics of the data by technology class.

We use M&A activity as a measure of the downstream side for patented technology from other firms. We identify acquisitions in the ICT equipment industry using the Securities Data Company's M&A data module, which covers all U.S. corporate transactions, public and private, since 1979. From this data we identify M&A deals in which either the target, the acquirer, or both firms have at least one patent in the ICT equipment industry between 1979 and 2010. We then

[22] The dropped classes correspond to roughly 10% of the entire patenting in ICT.

eliminate deals that are not of interest. The final sample includes 19,878 M&A deals from 1976 to 2010. Further details on the M&A data and the filters we apply are discussed in Appendix A4.

We are concerned that M&A is not the only channel for transferring ownership of patents between firms. Licensing and outright sale of patents are two other channels, both of which provide additional information about the market demand for ideas.[23] However, a comparison with Serrano's (2010) study leads us to believe that a merger is a very good proxy for demand. Serrano records that 13.5% of all granted patents are traded over their life-cycle; we obtain a similar scale of transfer (11%) through M&A activity, which suggests that over 80% (i.e., 11 ÷ 13.5 > .8) of the transfers in ownership of patents measured by Serrano occur due to M&A.

VI. Concentration and Other Measures[24]

In this section we describe the market structure, technology supply, and technology demand proxies we use in our empirical framework. In Table 2, we summarize the dataset. Patent stock concentration in a technology class is our main variable. We capture the patent stock concentration of granted patents in each technology class–year group as the share of top firms in the ICT equipment industry. More specifically, we create variables $C1_{stock}$, $C2_{stock}$, …, $C25_{stock}$, where CX_{stock} is the share of patents applied for by the top *X* firms within the technology class on or before that year and that were eventually granted. In each year we reselect the top firms; in other words, even though the number of firms used to calculate *CX* is kept constant at *X*, the set of firms may be different from period to period. We stop at $C25_{stock}$ because in many technology class–

[23] See Arora and Gambardella (2010) and Serrano (2010).

[24] Much of this section is a restatement of our section "Concentration and Other Measures" in our earlier study, "Composition of Innovative Activity in ICT Equipment R&D," as was referenced in the acknowledgments.

year buckets, the top twenty-five firms reach 100% of patent stock ownership in the early years of our sample. On average, the top twenty-five firms in a technology class–year bucket own 55% of the high-quality patents. There is considerable variation in this concentration over time.[25]

A source for downstream-path invention is the procurement of patents through acquisition of other patent assignees. Higher merger activity is indicative of a lower cost of absorbing ideas from acquired firms. We construct a measure of *Merger Intensity* to account for this phenomenon. The *Merger Intensity* in a technology class in a year is the ratio of total patent stock transferred through assignee acquisitions to the total stock of patents in that year. On average, each year around 1.1% of existing high-quality patent stock is transferred through M&A activity (see Table 2), with considerable variation across different sectors. Although this percentage may seem small, it is not in practice. We will show that around 12% of high-quality patents change hands through the M&A of patent assignees. The higher merger intensity is indicative of a lower cost of absorbing ideas from acquired firms.

We also have several classes of variables for upstream factors. For those regarding location of inventive activity, we use *Top 10 MSA Share*, the ratio of patents originating from the top ten Metropolitan Statistical Areas (MSAs), to measure the geographic concentration of patent origins. If metropolitan areas serve as a substitute for large firms, we expect the *Top 10 MSA Share* to have a negative impact on ownership concentration. On the other hand, if the geographic concentration of patent stock ownership is indicative of a concentration due to the presence of large firms, which may imply high entry costs, then we expect the *Top 10 MSA Share* to have a positive impact on patent stock concentration.

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[25] In this context, more general measures of concentration, including Gini coefficients and Herfindahl-Hirschman indexes (HHIs) for each patent class-year group, could be constructed. In Appendix C we discuss our choice of C25 further, repeat our analyses using these alternative measures of concentration, and discuss implications.

For firm entry variables, we examine patent-weighted entry level, by constructing two measures of entry on the basis of the previous patenting activity of the firm, namely, *new entry* and *lateral entry*. Firm *i* is considered a new entrant to technology class *j* in period *t,* if the firm does not have any patents in any of the ICT equipment classes prior to period *t* and has at least one patent in technology class *j* in period *t*. When such an entry occurs, we consider all patents of firm *i* in period *t* in technology class *j* to be patents by a new entrant and calculate the new entry share by dividing the total number of new entry patents by the total number of patents in technology class *j* in period *t*. Firms that have no prior ICT equipment inventive activity produce, on average, 3.7% of the patents stock in a technology class.[26]

Another upstream factor is economies of scope, which we capture with lateral entry. More specifically, we consider firm *i* a lateral entrant to technology class *j* in period *t* if the firm did not have any patents in technology class *j* prior to period *t*, had at least one patent in another ICT equipment technology class prior to period *t*, and has at least one patent in class *j* in period *t*. We then calculate the *lateral entry share* as the ratio of patents by lateral entrants in period *t* in class *j* to the total patent count in period *t* in class *j*. On average 2.7% of high-quality patents come from lateral entrants.

Entry of a firm may not fully materialize within one year, so we also construct entry variables within a four-year time window, in which we consider any entry over the previous period

[26] Note that in this setting the sample is restricted to high-quality patents, hence the entry variables capture entry into the high-quality patent pool rather than entry into the entire patent pool. In other words, a firm with many low-quality patents and no high-quality patent in prior periods would be considered a new entrant in the first period it produces a high-quality patent.

a new entry of the current period. The extended time window increases the new entry share from 3.7% to 25.8%, and lateral entry share increases from 2.7% to 7.7%.[27]

We should note that when combined, these two variables capture the inverse of the serial dependence of patenting by firms already in a technology class. In other words, considering the 3.7% new entry and 2.7% lateral entry averages, we deduce that on average 93.6% (i.e., 100 – 3.7 –2.7) of patents come from firms that already had patents in a technology class in prior periods. As a result, when we include both entry variables in the model, we also account for serial dependence.

The second class of entry variables is the growth in the number of firms active in a technology class. We calculate the growth in the number of firms over time. On average the number of firms has increased by 9% every year for both the U.S. and foreign firms.

The growth in the number of patents constitutes our third class of independent variables. On average the patent count has grown by 10% every year (10% in domestic and 12% in foreign firms). When we take into account the 9% average yearly increase in the number of firms, which is less than the 10% growth in patent count, we deduce that patent growth is coming from both entrants and incumbents.

The final class of exogenous variables are dummies for the presence of a big firm. We restrict attention to AT&T, Motorola, and IBM, the three leading firms at the outset of our sample. We include lagged indicators for their existence among the top five patent applicants. We see that the presence of AT&T is somewhat dwarfed by the strong presence of IBM: IBM is among the top

[27] The dramatic increase in new entry share is by construction. In the one-year measure the patent stock from only the entry year is considered, whereas in the four-year measure each entrant firms' patent stock is included for up to four years.

five patent applicants in 54% of technology class–year cells, whereas AT&T and Motorola are in the top five patent applicants in only 41% and 32% of the cells, respectively.

VII. Deconcentration of Patent Stock Share

VII.a. Historical Trends

To discuss examine how and why deconcentration occurred over time, we begin with a descriptive exercise. We present the broad changes in the distribution of patent stock shares over our sample period. At the top of the patent stock distribution, the number of firms that has more than 5% of shares in any technology class drops from sixty-six in 1986 to forty-seven in 2006.[28] The pertinent question is where does the drop shift to? Does it move to the middle or to the tail of the size distribution. We present these trends in Figure 2 by reporting a histogram of firms at various patent stock share levels. Panel A presents the full distribution. We see that at the left of the distribution there is an outward shift, which suggests that the number of firms with less than 5% shares have been increasing. However, when we zoom in to firms between 1% to 5% shares in Panel B, we observe that the number of such firms decreases. The only portion of the histogram that exhibits an increase is in the number of firms that has less than 1% patent stock share, which is reported in Panel C. These results suggest that over the last two decades of our data, the top firms, firms that have 1% or more of patent stock share, have lost patent stock share to the smaller, less well-known firms.

We observe this historical reduction in patent stock shares of leading firms also at the firm level. As illustration of this reduction, Figure 3 includes the firms that are among the top twenty patenting firms in 1986 or in 2007. Panel A includes firms that appear among the twenty both at

[28] For the purposes of this calculation, if a firm has more than 5% share in multiple classes, then the firm is counted multiple times, once for each class.

the beginning and the end of the sample. We observe that many of these firms go through a dramatic decrease in patent stock share, with the most dramatic decline happening to AT&T and Motorola. Some, though, maintain their patent shares, such as IBM's move from 4% to 6% in mid-1990s, and then back to 4% in the 2000s. Hitachi, Canon, and Panasonic exhibit a decline in the 1990s with a small recovery in 2000s.

The decline is more startling when we turn to Panel B: Firms appearing in the top twenty in 1986, do not in 2007, including Philips, General Electric, and NEC. These eleven firms end our sample period with less than half their initial ownership share. The emerging firms of the period, including Microsoft, Intel, and Broadcom, are presented in Panel C. These firms start with shares around 0.5% or less, and all end above 1% ownership share. However, none has increased to the levels of IBM, Motorola or AT&T of the 1980s. In short, yesteryear's leaders decline and some new emerging firms rise, but none of the new risers reaches the level of dominance of the past. Overall, there is a decrease in concentration.

We now focus on $C25_{stock}$, the share of top twenty-five firms in patent stock, as our measure of concentration.[29] Figure 4 illustrates the CX_{stock} values for technology class 385 (Optical Waveguides). The top line in Figure 4 represents the share of top twenty-five firms in the class ($C25_{stock}$), and the bottom line represents the share of the top firm only ($C1_{stock}$). The share of the top twenty-five firms has seen a decline from 54% in 1976 to 39% in 2007. In fact, we observe an overall deconcentration in twenty-nine of the thirty classes in our sample of high-quality patents. The values of $C25_{stock}$ increases in only class 358, facsimile and static

[29] The patent grants may come many years after a patent is applied for, and this delay is coined as the patent application-grant delay. The convention in the literature on patents is to use the patent application year as the year of the invention because the application year is closer to the actual creation of the idea; whereas the delay, hence the grant year, is a function of other factors including the workload and staffing issues at the USPTO. In this study, we follow this convention, and use the patents applied for and granted between 1976 and 2010.

presentation processing. All these trends suggest a deconcentration of ownership in patents in our sample period.

We now turn to Figure 5 to observe this deconcentration trend across all technology classes. Figure 5 shows the distribution of $C25_{stock}$ values across all technology classes for all high-quality patents in the ICT equipment sample. The mean value of the top twenty-five firms' new patent stock share across technology classes follows a gradual decline over the years from 65% in 1986 to 51% in 2007.

We now investigate potential causes of this deconcentration across technology classes. To investigate the role of dominant firms, we calculate a simple statistic, the number of firms that contribute 90% or more to the changes in $C25_{stock}$, the share of the top twenty-five firms, over our sample period. The results are presented in Table 3, which reports the changes for high-quality ICT equipment patents. We see that of the 29 classes with deconcentration, in only six classes are three or fewer firms responsible for 90% or more of the reduction in $C25_{stock}$. In the remaining 23 classes there is an industry-wide deconcentration trend, which suggests that the divestiture of AT&T, or another leading firm, cannot be the sole reason for the established deconcentration. The qualitative observations remain the same when we remove the restriction on the high-quality patents and consider the entire patent sample.

VIII. Role of Mergers and Acquisitions

We now examine the M&A data to proxy for the downstream path for invention and to see the magnitude of patent transfers through M&A in the ICT equipment industry. In 1,881 of the M&A deals (9%) in our sample, both the acquirer and the target firm have at least one ICT equipment patent, and in 1,127 deals (6%) only the target has ICT equipment patents. (Transfers of patents take place in approximately one out of seven times (i.e., 3,008 out of 19,878) for M&A deals involving ICT equipment patent holders –See Appendix A4, and Table A3).

To assess the share of patents transferred through M&As, we report the patent stock for the ICT equipment industry and for the firms that were targeted in an M&A deal in Table 4. We calculate the patent stock using the declining balance formula, which is standard in the literature, and is described above in the Framework Section. The total patent stock of acquirers includes patents by the acquirers independent of the year they make acquisitions. As an example, the patents of a firm that makes an acquisition in 1997 are accounted for in the patent stock before, during, and after 1997. On the other hand, the target patent stock is only included in the year in which the target firm is acquired. Patents created before an acquisition by the target firm transfer to the acquiring firm. Note that, unlike in earlier sections, in which we consider the patents of only the top twenty-five firms, Table 4 reports patents acquired by all firms.

Table 4 shows that the stock of patents that changed hands through M&A transactions increases over time in nominal terms, though with some fluctuations in the 1980s. Yet the share of patents transferred with respect to the entire stock of ICT equipment patents gradually decreases from approximately 20% in the early 1980s to 12% in 2007. This observation holds for both the entire sample and high-quality patents, with a share of the transfers 2% higher across the board for high-quality patents.

The ratio of transfers increases dramatically when we change the denominator from the entire ICT equipment patents to patents of firms that conduct an acquisition. In the early years of our sample, the size of transferred patents corresponds to more than 30% of the acquirer patent stock, which decreases to 19% in 2007. We see a similar trend with a slightly lower transfer ratio in the entire patent sample.

The transfer of 12% of an industry's patents through M&A activity is a significant source of ownership change. However, we can compare the 14% approximate decrease in the ownership share of the top twenty-five firms in cumulative patent stock to the 12% of patents being transferred through acquisitions. Given that not all of the transferred patents go to the top twenty-five firms, the magnitude of transferred patents is not great enough to revert the deconcentration trend we established in our analyses.

These findings also raise interesting open questions about other factors contributing to deconcentration. Specifically, what role will lateral and new entry play in the future? There is an average decline in new entry and lateral entry over time. The new entry share starts at around 5% in 1986 and gradually drops to 1% in 2007. The lateral entry share follows a similar declining trend, with 3.4% in 1986, and 0.7% in 2007. It is possible that the factors of lateral entry and new entry only reflected a one-time change that has largely played itself out. If both have declined permanently, then neither factor can play as large a role in the future. These observations are consistent with Klepper's (1996) industry evolution theory, in which manufacturing cost advantages accrue to incumbents, increasing barriers to entry, hence drying new entry as the industry evolves. These observations are also consistent with the increase in the strategic use of patents following the changes in the IP strategy during the 1980s. That change in strategy affected all firms in this sector, spreading outwards from the semiconductor sector to others (Hall and Zeidonis, 2001).

IX. Composition of Patent Stock: The Model

We now turn our attention to combining downstream and upstream explanations in a fixed effects model. Table 2 presents the summary statistics used in the patent stock model. We see that the number of firms grows at a pace of 9% each year and the number of patents grows at a 10% rate.

As expected, recycling patents over their lifetime results in a lower new entry and lateral entry patent stock share: Each year, 3.7% of the patents in a technology class belongs to new entrants, and another 2.7% belongs to lateral entrants. This implies that each year roughly 94% of the depreciated high-quality patents stock belongs to firms that were active in the technology class in a prior year. When we increase the entry window to four years, the new entry increases six-fold to 26% per year, and lateral entry increases to 7.7%. As an indicator of the incumbent behavior, the positions of IBM, AT&T, and Motorola appear strong by appearing among the top five firms in 54%, 41%, and 32% of technology class-year buckets, respectively.

We now combine the various factors in the following fixed effects model:

$$(C25_{stock})_{jt} = \beta_0 * (\text{M}\&A\ Intensity)_{jt} + \beta_1 * (\text{Top 10 MSA Share})_{jt} + \beta_2 * (\text{New Entry})_{jt}$$
$$+ \beta_3 * (\text{Lateral Entry})_{jt} + \beta_4 * (\text{Growth})_{jt} + \beta_5 * \delta_{j,t-1,AT\&T} + \beta_6 * \delta_{j,t-1,,Motorola}$$
$$+ \beta_7 * \delta_{j,t-1,IBM} + \gamma_j + \theta_t + \varepsilon_{jt},$$

where, once again, *j* is the technology class indicator and *t* is the time indicator. The list of regressors include new entry and lateral entry into technology classes, growth measures, and indicator variables for the presence of big firms, namely AT&T, Motorola, and IBM. We use two sets of entry measures, defined in one-year and four-year time windows. Similarly, we use two sets of growth measures, one for growth in the number of firms and a second for growth in the number of patents. We further divide these growth variables into two components—those for U.S.-based firms and those for their foreign counterparts. The growth measures are highly correlated; therefore, we use either the firm-based or the patent-based measure in a single model. We also include the M&A intensity, the measure of transferred patents through M&A activity in a technology class.

In Table 5, we present the fixed effects model of patent stocks. The dependent variable in the model is $C25_{stock}$.[30] We clustered the standard errors by technology class.[31] The columns differ in the inclusion of different patents and the number of firm growth variables, as well as the time windows for the entry variables.

Figure 6 presents the set of results for the fixed effects, which lends themselves to an interpretation consistent with historical facts. We observe a 4% deconcentration during the 1980s, which coincide with the PC boom and the scale up of the Venture Capital activity in Silicon Valley. A slowdown in the early 90s, followed by an additional 5% deconcentration during the late 90s ramp up towards the dot-com crash are also consistent with the conventional wisdom about the timing of boom and bust. Eventually, the time effects plateau following the crash. Though many factors shape these estimates and prevent us from making a causal inference, these estimates are consistent with a plausible historical story about a potential role for macroeconomic factors, namely, boom and bust—especially boom. They are consistent with the story that booms played a role in reshaping the concentration of economic activities in ICT equipment markets.

Before discussing the impact of other covariates below, we note that, on average, the concentration of a technology-class in a year-group is 8.12% (= – 9.61% – (– 1.49%)) lower in 2007 than in 1987. We will compare the impact induced to this time impact of 8.12% to gauge a relative sense.

As our downstream-side measure, M&A intensity does not have a statistically significant impact on market concentration. This is true for both the entire sample and the high-quality patents,

[30] All models include class and time fixed effects. In Appendix C we report results with a linear and a quadratic time trend instead of time fixed effects. The qualitative results remain the same in these alternative specifications.

[31] Two-way clustering of the standard errors by class and time does not change our statistical inferences.

which implies that demand for ideas does not have a big impact on the concentration of ownership.[32]

On the upstream side, the impact of *Top 10 MSA share* is both statistically and economically significant across specifications for the high-quality patents, but not overall patenting. An average level of *Top 10 MSA share*, 50%, results in increased concentration of 18.22% (= 0.50 * 0.36), which is more than twice the magnitude of the deconcentration induced by time (8.12%). This result holds both for the top quartile and top decile patent samples; however, in the entire sample of patents, the *Top 10 MSA share* does not have a statistically significant impact on concentration. Overall, we conclude that urban areas do not act to decrease concentration.

The results on new entry are mixed for the one-year entry window but are robust for the four-year entry window. In the entire sample of patents, the new entry has a statistically and economically significant impact on the concentration: A yearly 2.3% entry (the average level) results in a 0.8% (= 0.023 * 0.38) yearly decline in concentration; but, when we restrict the sample to high-quality patents, new entry share loses its statistical significance in some of the models. Nevertheless, new entry every four years is both statistically and economically significant. The average four-year new entry of 26% results in an 8.4% (= 0.25 * 0.32) reduction in concentration, which is roughly the same level of deconcentration induced by time fixed-effects, with the difference that the new entry impact repeats every year, whereas the time fixed-effect captures the cumulative one-time impact.

[32] In unreported results we found that, by restricting the sample to the 10% highest-quality patents, M&A intensity has a marginally significant negative impact on concentration, but even this impact is economically small.

The increase in the number of firms is also important, though this result is not robust across models and different samples that are based on patent quality. Similarly, the increase in the number of patents also lacks statistical significance.

Lateral entry, our proxy for economies of scope, is associated with an increase in the ownership of top firms, though the impact is not statistically significant. This result may be driven by the fact that firms conducting lateral entry operate in more than one segment of the industry; hence, they are expected to have a larger operation than others, and the lack of statistical significance may be attributed to the slow pace of change in the stock of patents. Note that lateral entry in this context means having a high-quality patent in one ICT equipment class and producing a new high-quality patent in another ICT equipment class in which the firm did not previously have high-quality patents; having low-quality patents in either industry has no effect on the entry measure among high-quality patents.

The models suggest that the existence of AT&T as one of the top-five patent owners in the prior period does not have a statistically significant impact on the concentration of the patent class, which is consistent with our earlier trend analyses. The coefficients of the IBM and Motorola indicators are also not significant. In sum, no evidence suggests prior large firm leadership caused deconcentration.

The main results across all models show that growth in new firm patent stock shares and the growth in the number of firms are important drivers of deconcentration, suggesting that a smaller transaction cost for entry results in lower patent stock concentration. Lateral entry and Top 10 MSA Share work in the opposite direction of new entry by increasing the concentration of patent stock. When we turn our attention to the entire sample of patents, we obtain similar results for the growth in the number of firms; the impact of lateral entry and *Top 10 MSA share* increases concentration.

X. Conclusion

Although our study has several inherent limitations in that we treat the USPTO classification system as given; we cannot test assumptions related to different definitions of technology classes; and our data includes patents granted since 1976, a restriction which truncates the patent stock variable for the early years of our sample and therefore prevents investigation of the earlier trends and causes, we *are* able to provide some characterization of long-term trends related to where the concentration inventive ideas originate in the ICT equipment industry and we *are* the first to aggregate all the data and identify technology classes at the owner level. Analyzing the concentration in granted patents in this industry from 1976 to 2010, we compare measured changes against popular assumptions about the size and scale of changes in invention.

Overall, we find a substantial decline in concentration. The data show that deconcentration arises in every measure of the trend and is present in the cumulative ownership of active patents. We also show that the size and scope of the changes vary considerably, with some segments of ICT equipment undergoing much more dramatic changes in concentration than other segments.

We analyze evidence about the causes of this change. The statistical evidence is consistent with explanations that stress the role of upstream path changes more than downstream path changes. We present evidence that new entry accounts for part of this deconcentration. Most important, we reject the notion that foreign (i.e., non-U.S.) firm entry is the sole cause of the change. We also reject the notion that one antitrust case, one company’s strategic error, or the break-up of one large leading innovator of yesteryear accounts for this change in structure. Furthermore, we show that the deconcentration results, as well as the results on the drivers of deconcentration, hold in the entire patent sample and in the high-quality patent sample, across a variety of concentration measures.

This also is the first study to investigate the extent of the potentially countervailing M&A mechanism using a census of the M&A activity in the ICT equipment industry. First, we show that there is a considerable transfer of patents through M&A, which relates to the literature on R&D incentives in an M&A context on one hand, and the start-up commercialization framework of Gans, Hsu, and Stern (2002) on the other. We then show that the size of the patent transfer through M&A is not enough to revert the composition of ownership to its pre-deconcentration levels. We conclude that the leading firms' strategies to externalize R&D activity has not reversed the trend towards deconcentration. Furthermore, M&A intensity does not have a statistically significant impact on the ownership concentration of ideas.

Finally, the results of deconcentration of ownership relate to the literature on DTL and, more broadly, to debates about the causes of market leadership and incentives in innovative activities. By distinguishing between product market leadership and technological leadership and then focusing on the latter, we provide evidence of increased competition in the ideas market. This increased competition may be indicative of higher incentives to innovate, and, hence, higher levels of inventive activity under a model in which incentives increase monotonically with greater competition. These results are also consistent with the conventional wisdom about trends in the ICT equipment market, including the importance of the 1980s PC boom, the ramp up of the 1990s Internet boom followed by the dot-com crash, and the stable period that followed.

Based on these results, one may ask what causes new entry into new inventive areas by firms that previously have had little inventive experience. The changes in entry levels may be due to various factors, including increased technological opportunities or product market demands;

easier access to external funding sources, such as Venture Capital funding; and demand from firms with established product market presence for external invention. The increased M&A activity could be a long run response to changes in the patent system, leading to changes in patenting activity, and, subsequently, an increase in markets for technology. This diffused throughout the ICT sector during the 1980s and 1990s. This question constitutes the next step in analyzing the innovation markets and must be left for future work.

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Table 1: ICT Equipment patent technology classes considered

Class	Description
178	Telegraphy
330	Amplifiers
331	Oscillators
332	Modulators
333	Wave transmission lines and networks
334	Tuners
340	Communications: electrical
342	Communications: directive radio wave systems and devices (e.g., radar, radio navigation)
343	Communications: radio wave antennas
348	Television
358	Facsimile and static presentation processing
367	Communications, electrical: acoustic wave systems and devices
370	Multiplex communications
371	Error Detection/Correction and Fault Detection/Recovery
375	Pulse or digital communications
379	Telephonic communications
380	Cryptography, subclasses 255 through 276 for a communication system using cryptography
381	Electrical Audio Signal Processing Systems and Devices, subclasses 1+ for broadcast or multiplex stereo
385	Optical waveguides
398	Optical communications
455	Telecommunications
700	Data processing: generic control systems or specific applications
701	Data processing: vehicles, navigation, and relative location
702	Data processing: measuring, calibrating, or testing
703	Data processing: structural design, modeling, simulation, and emulation
704	Data processing: speech signal processing, linguistics, language translation, and audio compression/decompression
705	Data processing: financial, business practice, management, or cost/price determination
706	Data processing: artificial intelligence
707	Data processing: database and file management or data structures
708	Electrical computers: arithmetic processing and calculating
709	Electrical computers and digital processing systems: multicomputer data transferring
710	Electrical computers and digital data processing systems: input/output
711	Electrical computers and digital processing systems: memory
712	Electrical computers and digital processing systems: processing architectures and instruction processing
713	Electrical computers and digital processing systems: support
714	Error detection/correction and fault detection/recovery
715	Data processing: presentation processing of document, operator interface processing, and screen saver display processing
716	Data processing: design and analysis of circuit or semiconductor mask
717	Data processing: software development, installation, and management
718	Electrical computers and digital processing systems: virtual machine task or process management or task management/control
719	Electrical computers and digital processing systems: interprogram communication or interprocess communication
720	Dynamic optical information storage or retrieval
725	Interactive video distribution systems
726	Information security

Table 2: Summary statistics of key patent *stock* variable

Variable	Mean (%)	Std. Dev. (%)
C5_stock	28	10
C25_stock	55	13
HHI	30,000	21,400
Merger Intensity	1.1	1.6
Patent Share by Entrants		
New Entrants - 1 year	3.7	3.0
New Entrants - 4 years	25.8	30.4
Lateral Entrants - 1 year	2.7	2.1
Lateral Entrants - 4 years	7.7	5.8
Growth in No of Firms		
Total	9	6
US only	9	7
Foreign only	9	8
Growth in No of Patents		
Total	10	10
US only	10	11
Foreign only	12	14
Geography		
Top 10 MSA share	50	12
Top 10 County share	16	10
Firm in Top 5 in Previous Period		
AT&T	41	49
Motorola	32	47
IBM	54	50

Notes: The sample includes patent stock values from 1986 to 2007, calculated from patent applications in top quartile quality level in the period from 1976 to 2007 that are ultimately granted by USPTO on or before 2010. The averages are across the thirty ICT equipment industry patent technology classes and years. $C25_{stock}$ is the *patent stock* share of top twenty-five companies within a cell. The HHI is calculated within each cell. *New Entry Share* is the share of patents in a technology class in a period that are held by assignees that did not have any patents in any ICT equipment industry patent technology classes in prior periods. *Lateral Entry Share* is the share of patents in a technology class in a period that are held by assignees that had patents in other ICT equipment industry patent technology classes in prior periods but did not have any patents in the current technology class in an earlier period. Growth is measured within each technology class across two consecutive calendar years. The firm dummies indicate the presence of the firm among the top five *patent stock* holders in the previous period.

Table 3: No. of Companies accounting for 90% of change in $C25_{stock}$

No. of Companies	No. of Classes
1-3	6
4-19	14
20-25	9
Total	29

Notes: The number of ICT equipment industry patent technology classes that went through a deconcentration of *patent stock* ownership from 1986 to 2007, grouped by the number of companies that account for the 90% of the deconcentration. The sample includes the highest quartile of patents, where quality is measured by citations received.

Table 4: Cumulative ICT equipment patent stock

Year	Patent Stock			Share Transferred	
	All ICT	Acquirer	Target	Target/ All ICT (%)	Target/ Acquirer (%)
1979	2,741	30	2	22	38
1980	3,383	36	3	20	36
1981	3,945	268	39	20	35
1982	4,498	1,062	87	20	33
1983	4,956	1,289	82	19	32
1984	5,402	1,841	90	19	32
1985	5,897	2,108	116	19	33
1986	6,409	2,486	318	19	32
1987	7,009	2,896	357	18	30
1988	7,773	3,497	321	18	30
1989	8,709	4,169	299	18	29
1990	9,619	5,100	272	18	30
1991	10,506	5,650	302	19	31
1992	11,490	6,236	300	18	30
1993	12,534	6,950	279	18	29
1994	14,207	7,948	289	19	29
1995	16,744	9,612	310	19	30
1996	19,762	11,615	385	20	31
1997	23,611	13,809	614	19	30
1998	27,351	15,959	1,024	19	30
1999	31,306	19,989	1,348	19	28
2000	35,736	23,123	1,792	18	27
2001	40,028	25,696	1,771	17	26
2002	43,444	27,572	1,925	16	25
2003	45,960	29,317	1,860	15	24
2004	48,074	30,675	2,909	14	22
2005	49,390	31,624	2,687	13	21
2006	48,904	31,294	3,494	12	20
2007	45,944	29,316	3,412	12	19

Notes: Cumulative ICT equipment industry *patent stock* transfers through mergers against the entire ICT equipment industry *patent stock* from 1979 to 2007, at the highest quartile patent quality level, where quality is measured by citations received. The *patent stock* is the discounted sum of unexpired patent holdings in the sample. The M&A activity includes deals from SDC's M&A module between 1979 and 2010, in which the target has at least one ICT equipment industry patent between 1976 and 2007. The sample includes only the following transaction forms: merger, acquisition, acquisition of majority interest, acquisition of assets, and acquisition of certain assets. Deals that include a firm from the financial industry or a utility firm on either side, or a subsidiary as a target, are dropped from the sample.

Table 5: OLS analysis of patent *stock* ownership concentration

Dependent Variable: $C25_{stock}$	(1)	(2)	(3)	(4)
M&A Intensity (Stock of patents transferred in M&A / All ICTE Patent Stock)	-0.24	1.46	4.14	4.18
	(10.03)	(9.69)	(10.94)	(10.73)
Location Top 10 MSAs	36.44	37.02	36.62	37.63
	(12.96)***	(12.93)***	(12.80)***	(12.72)***
New Entry Share (4 years)	-32.42	-32.86	-37.44	-37.20
	(8.93)***	(8.61)***	(8.11)***	(8.16)***
Lateral Entry Share (4 years)	1.69	2.07	-4.77	-4.37
	(4.66)	(4.36)	(5.56)	(5.49)
Total Growth in No. of Firms	-5.25			
	(7.78)			
US Only		3.72		
		(5.68)		
Foreign Only		-8.91		
		(3.46)**		
Total Growth in No. of Patents			6.53	
			(5.17)	
US only				8.27
				(3.78)**
Foreign only				-1.22
				(2.30)
Lagged Dummies if Firm is in Top 5				
AT&T	-1.23	-1.39	-1.20	-1.16
	(0.94)	(0.94)	(0.97)	(0.95)
Motorola	-1.45	-1.47	-1.40	-1.47
	(0.89)	(0.88)	(0.89)	(0.89)
IBM	-1.63	-1.64	-1.57	-1.48
	(1.61)	(1.55)	(1.63)	(1.59)
R-Squared	0.61	0.62	0.62	0.62
N	660	660	660	660
Number of Classes	30	30	30	30

Notes: Regressions are ordinary least squares (OLS), with S.E. in parentheses. ***, **, * indicate significance at the 1%, 5%, and 10% levels respectively. Standard errors are clustered by class. An observation is a patent technology class and a calendar year. N is 660. Each model includes technology class fixed effects and time fixed effects. The sample includes patent stock values from 1986 to 2007, calculated from the highest quartile of patents in the period from 1976 to 2007 that are ultimately granted by USPTO on or before 2010, where quality is measured by citations received.

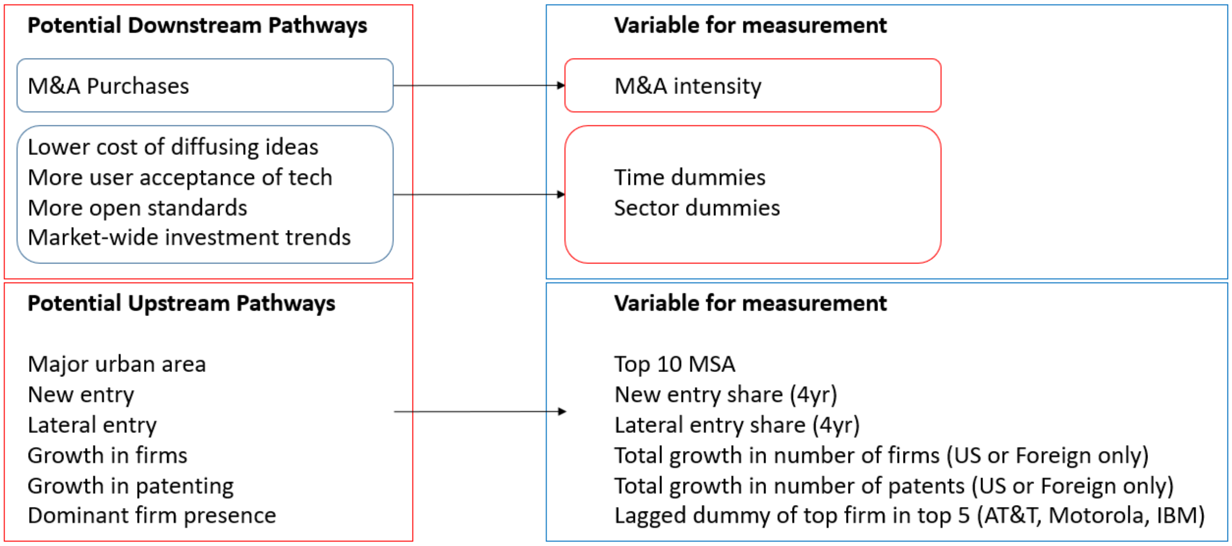

Figure 1: Map to Analysis

Notes: The Figure provides the correspondence between the concepts as defined in Section IV and their empirical counterparts as defined in Sections V and VI.

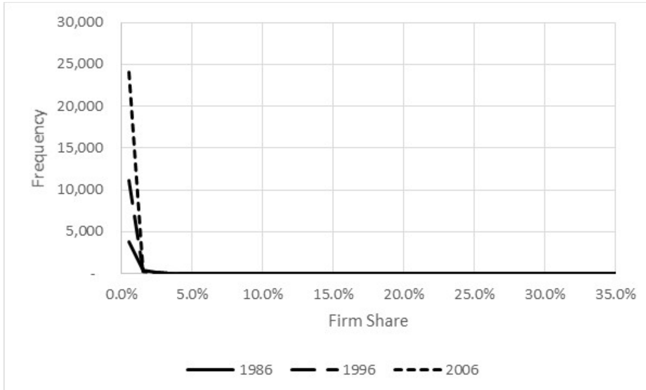

Figure 2 - Panel A, Entire graph

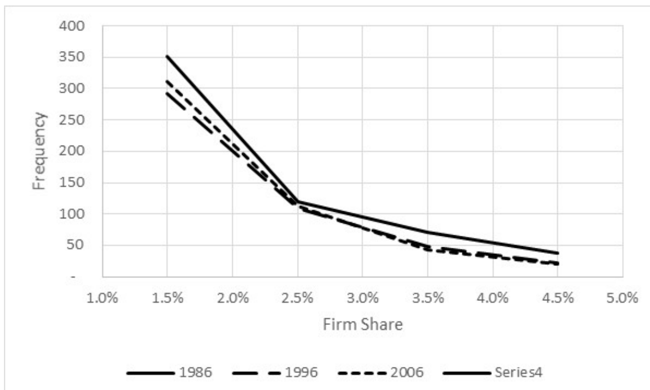

Figure 2 - Panel B, focusing on 1% to 5%

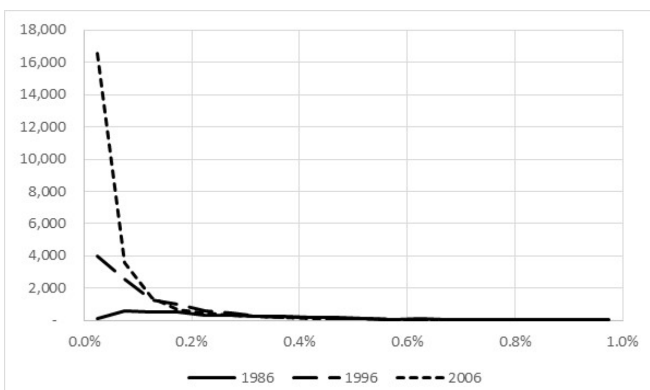

Figure 2 - Panel C, focusing on 0% to 1%

Figure 2: Histogram of Firm Ownership Shares

Notes: Panel A presents the frequencies for the entire distribution, ranging from 0% to 35% shares. Panel B reports shares between 1% to 5%, and Panel C reports shares less than 1%. The sample includes patent applications 1976 to 2007 that are ultimately granted on or before 2010, at all levels of patent quality. The level of observation is a firm-technology class level. In other words, a firm is counted in a bin if it has the specified amount of ownership share in that bin for a technology class. If a firm has shares in multiple technology classes, then it is counted multiple times. Only activity within the top quartile of patent stock is considered. The patent stock is the discounted sum of unexpired patents.

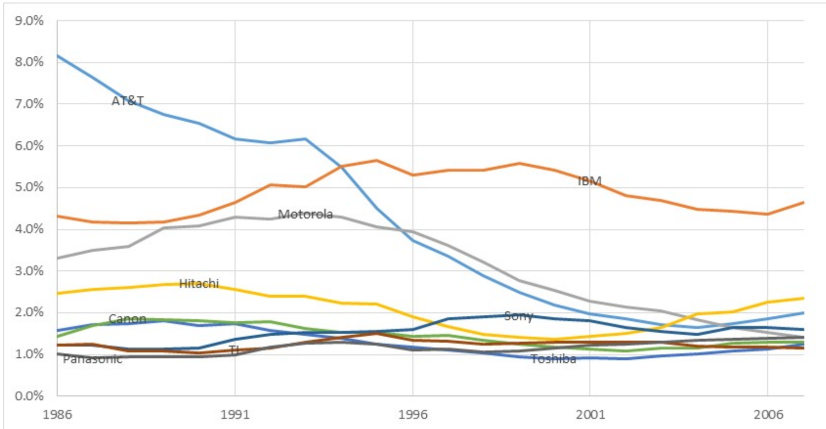

Figure 3 - Panel A, Top 20, at beginning and at end.

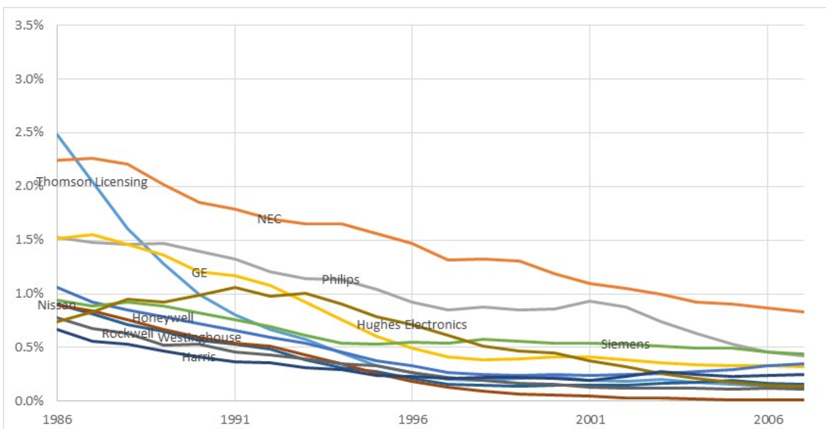

Figure 3 - Panel B, Top 20, at beginning only, not at end.

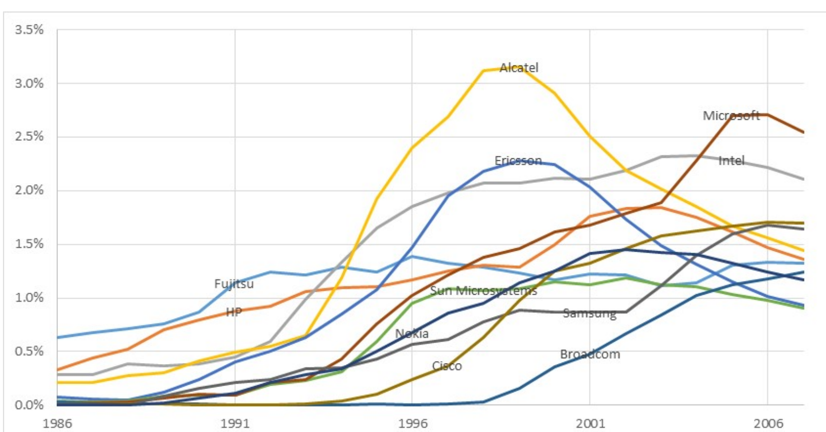

Figure 3 - Panel C, Top 20 at end only, not at beginning.

Figure 3: Historical Leadership Positions of Top 20 Firms

Notes: Panel A presents nine firms that maintain their rank among the top twenty firms from 1986 to 2007. Panel B includes eleven firms that were among top twenty firms in 1986 but lost their prominence by 2007. Panel C also includes eleven firms that appear among the top twenty firms in 2007, but not in 1986. The sample includes patent applications 1976 to 2007 that are ultimately granted on or before 2010, at all levels of patent quality. Leadership is defined as being among the top twenty firms in patent stock ownership in 1986 or in 2007 within the entire ICT equipment patent sample. There are thirty-one firms that fall into this definition of leadership. The figure presents patent stock ownership shares within the entire ICT equipment patents (i.e. all thirty technology classes). The patent stock is the discounted sum of unexpired patents.

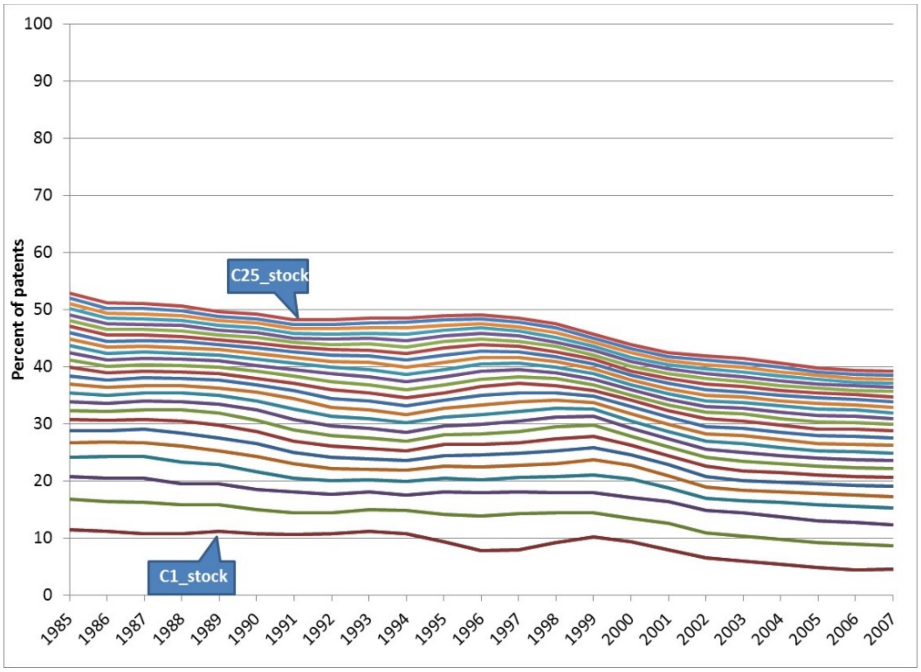

Figure 4: Patent Stock Concentration Levels (Technology Class 385)

Notes: The sample includes patent applications from the Optical Waveguides technology class (class 385) from 1976 to 2007 that are ultimately granted on or before 2010, at all levels of patent quality. The concentration is measured by the share of top *i* firms in terms of patent stock within each year, where *i* ranges from one to twenty-five. The patent stock is the discounted sum of unexpired patents.

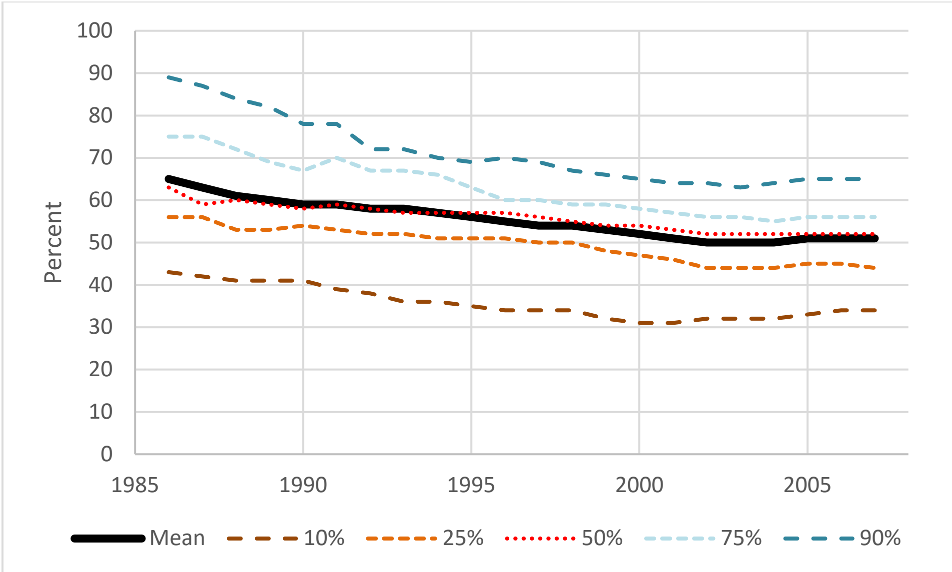

Figure 5: Distribution of $C25_{stock}$ values

Notes: Evolution of the patent application *stock* share for top twenty-five firms. Each observation corresponds to a calendar year. The solid black line reports the average value across patent classes. The dashed lines report the percentiles at the indicated level. The sample includes the highest quartile patents in the thirty patent technology classes in the ICT equipment industry, where quality is measured by citations received. The *patent stock* of a firm is the discounted sum of its unexpired patents that are applied for between 1976 and 2007 and are ultimately granted on or before 2010.

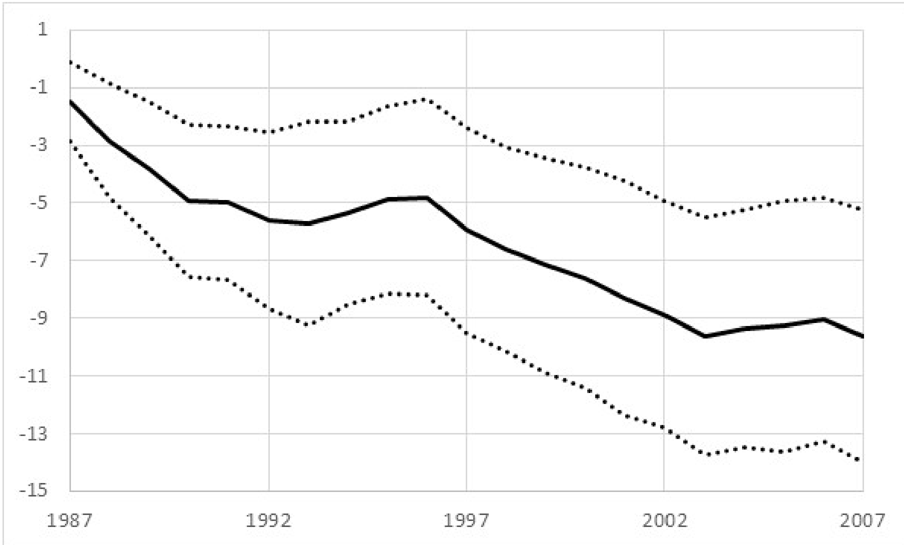

Figure 6: Patent stock – time fixed effects coefficient estimates

Notes: Coefficient estimates of time fixed effects from Model 1 in Table 4. Regressions are ordinary least squares, the solid line represents the coefficient estimates, and the dashed lines indicate the 95% confidence intervals obtained from standard errors clustered by class. An observation is a patent technology class and a year. N is 660. Each model includes technology class and time fixed effects. The sample includes the highest quartile of patents in the period 1986 to 2007 that are ultimately granted by USPTO on or before 2010, where quality is measured by citations received.