Technological Leadership (de)Concentration: Causes in ICTE

Yasin Ozcan

NBER and MIT
1050 Massachusetts Avenue, Cambridge, MA 02138, USA
ozcan@mit.edu

Shane Greenstein

Harvard Business School
Soldiers Field Road, Boston, MA 02163, USA
sgreenstein@hbs.edu

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Abstract

Using patents as indicators of inventive activity, this article characterizes the concentration of origins of invention from 1976 to 2010, and how these changed over time. The analysis finds pervasive deconcentration in virtually every area related to ICT, but it can explain only a small part of this trend. Deconcentration happens despite the role of lateral entry by existing firms. New firm entry drives part of the deconcentration, but this alone cannot explain the change. A single supply factor in the market for ideas, such as the breakup of AT&T, also cannot explain the trend. Finally, eleven percent of patents change hands through mergers and acquisitions activity, but this does not make up for the declines in concentration in the origins of invention.

Introduction

The market structure for the Information and Communications Technology (ICT) equipment industry has undergone enormous change in the last four decades. Thirty years ago, most innovation took place in established firms, in large laboratories such as Bell Labs and IBM Labs (Rosenbloom and Spencer, 1996). Decades ago, such labs began to lose their prominence to widespread, decentralized, and small-scale innovators. The trend goes by many names in many analyses. In this study we use the label "divided technical leadership," or DTL for short. This is the framework put forward in Bresnahan and Greenstein (1999), which argues that DTL contributes to high rates of firm entry and exit, and that may occur without changing the concentration at the platform level. DTL plays a key role in shaping a market environment that nurtures open innovation (Chesbrough, 2003), supports open and proprietary platforms (Gawer, 2010, Greenstein, 2010), and encourages "innovation from the edges" (Greenstein, 2015). DTL also contributes to a market structure in which a dispersed set of market participants produces a range of new innovative prototypes for potential acquisition, so it plays a key role in the externalization of R&D by large firms, who use acquisitions of smaller firms for many of their innovative activities (Gans, Hsu, and Stern, 2002). Firms such as Cisco, IBM, and Apple participate in such activities, each of which have made more than one hundred acquisitions over the last two decades.

While the presence of DTL has received notice, its causes have not been examined. In part this is due to the slow pace of change in market structure. Large scale DTL did not arise instantaneously; rather, it has gradually emerged in different parts of ICT markets, and only over long time spans – several decades – would an observer expect stark differences to become apparent, and amenable to statistical analysis. Against such challenges in observation, this study offers the first statistical information and econometric analysis of the long run causes behind DTL.

Accordingly, the research goals are both descriptive and causal, and measurement challenges determine the lengths we can pursue in both.

We first establish some novel facts. Does statistical evidence of long-term change show a deconcentration in the sources of inventive ideas, as held by conventional models of DTL? The article characterizes the concentration in the origins of inventions in the ICT equipment industry in a given year. Next we describe changes over time.

Finding long term trends consistent with the increasing importance of DTL, the study turns to a second question: what factors determine the concentrated supply of, and concentrated demand for, inventive ideas, and how do these factors drive change? 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 on the relation between the supply of invention and DTL. More specifically, we ask the following questions: does economies of scope, product market leadership, entry by domestic and foreign firms, or location influence concentration in invention? In addition, we also test hypotheses about demand side factors: does changes in the demand for ideas from 1976 to 2010 impact the deconcentration of invention? If so, in which direction the impact happens?

To construct measures of the origins of invention, the study examines the concentration of granted patents in ICT equipment in the period from 1976 to 2010, which accounts for roughly 14 percent of all US patents. The study utilizes a data set constructed from XML and text files of patents granted by the United States Patent and Trademark Office (USPTO) between 1976 and 2010. The data covers four more recent years than the NBER patent data files, the standard data source for many studies on patents.[1] The novel length of time covered is essential for realizing our research goals, as the economic forces should manifest in slow changes, if at all, and at varying

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

paces in different technical areas. In addition, this length of time accounts for a unique event, the dot-com boom, which is coincident with the acceleration in patenting in the late 1990s. Finally, the new data contains standardized patent assignee names that enable patent data to be linked to other information about mergers and acquisitions (M&A) activity. As a result, mergers of both publicly traded and private firms can be examined.

The study supports the prevailing view about historical trends in DTL. We find a trend in deconcentration in the cumulative ownership of active patents. The analysis measures considerable variation in the size and scope of the changes, with some segments of ICT equipment undergoing dramatic changes. For example, while on average the top twenty-five firms accounted for 59 percent of the patent stock in 1986, the top twenty-five firms accounted for only 50 percent of the patent stock by 2010. Furthermore, the trend emerges in starker terms when we restrict the sample to high-quality patents, with a decline in top twenty-five firms' ownership from 65 to 51 percent in the patent stock over the same period.[2]

Why does this deconcentration arise? On the demand side, we look at the demand for inventive ideas by examining the merger 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.[3] Accordingly, we perform a (first-ever) census of such merger activity for ICT equipment, involving extensive data-matching (described below). The study finds that M&A activity results in the transfer of approximately 11 percent of the entire patent stock and 12 percent of the high-quality patent stock in the ICT equipment industry. Though the intensity of patent

[2] This result also holds for the flow of new patents created each year, as opposed to the patent stock, i.e. all the active patents of firms. In the remainder of this study we report results only for the patent stock, and leave the analyses on patent flow to Appendix B.
[3] See Ahuja and Katila (2001) and Cassiman and Valentini (2016), for open innovation, and Ozcan (2016) for transfer of invention through M&A activity.

transfer through M&A is associated with a slight decrease 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 demand for externalized invention, cannot explain variance in concentration between segments. We conclude that, while the trend towards deconcentration has not been due to, or reversed by, firm strategies to externalize R&D activity.

On the supply side we ask about several causes: does economies of scope, reduced entry costs, decline in leading firms, or the location of the invention drive this 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.[4] We use such lateral entry as a proxy for economies of scope and find evidence that ownership concentration *increases* with lateral entry, i.e., that economies of scope are not a cause of deconcentration. Next we examine evidence that *de novo* firm entry caused it, and we find mixed evidence. There is little evidence that non-US firm entry caused the change, which is another common hypothesis (reflecting a growth in imports and exports in the US economy over this period).[5] Rather, 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 US. 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: does the decline in the importance of the very largest firms merely reflect a decline in their importance in downstream

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

[5] 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 US patent due to the location of its US-based subsidiary. As with the prior literature (e.g., Hall, 2005), we focus on changes due to US patents with US assignees and non-US assignees, and examine whether the surge in patenting with Asian and European assignees accounts for change.

markets?[6] The preponderance of evidence suggests this is not the primary cause of change (though we also find a few exceptions). More specifically, we find that long-term trends in deconcentration cannot be fully accounted for by the divestiture of AT&T, or the loss in commercial leadership at IBM, Motorola, or any other recognizable firm in the industry. 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.

Relation to prior research

Our study relates to the research streams in two main channels. 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,[7] 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, the impact of M&A activity on the technological leadership relates to the literature on R&D incentives in the shadow of M&A and to the literature on start-up commercialization, also noted above. We differ from prior literature with our focus on understanding the causes behind changes in technical leadership in more recent decades. Finally, this is the first study to put these together. That is, we investigate the extent of, and causes behind, deconcentration in invention in the ICT equipment industry, and the potentially countervailing M&A mechanism.

We follow prior research that considers the resource-based and industrial organization streams together by considering industry and firm effects in a unified framework.[8] We differ from Skilton and Bernardes (2015), however, in that we distinguish between technology markets and product markets, and stress competition and entry into the former instead of the latter.

[6] See Miller (2006) for the relation between technology and product markets of firms.
[7] Greenstein, 2010 and 2015 review the literature on computing and commercial Internet, in particular.
[8] See e.g. Mauri and Michaels (1998), Hashai (2015), and Misangyi *et al.* (2006)

We further build on prior research into patenting, which touches on related themes, but has not examined the sources of deconcentration. Kortum and Lerner (1999) associated the increase in US patenting activity to an increase in US innovation and to changes in the management of R&D, which may have included actions such as reallocating efforts to more applied problems with higher patent yields. Kim and Marschke (2004) concluded that the increased patenting activity was due to increases in R&D in some sectors and increases in the rate of patenting in the computing, electronics, and auto sectors. Hall (2005) found that growth occurred in complex product industries such as telecommunications and concluded that this increase also spilled over to those firms' patenting behavior in other industries.

In our study, in contrast, we focus on the distribution of the increase in patenting between firms within each technology class; in other words, we differ in our focus on technical leadership in the technology class level, and its concentration. Indeed, our up-to-date data on patents allow us to answer an open questions posed by Hall (2005), namely, "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?"

The deconcentration results also relate to the research stream on how incentives change with competition. We provide evidence of the increased competitive conditions in the ideas market. This increased competition may be indicative of higher incentives to innovate. However, there are also limits. The 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). Our results are consistent with both.

The discussion of the M&A activity of the established firms in our study relate to the start-up commercialization framework of Arora, Fosfuri, and Gambardella (2004); Gans, Hsu, and Stern

(2002). This research posits that a startup innovator with a successfully developed, commercial technology faces a choice between competing with incumbent firms in the market and cooperating through selling or licensing the technology to the incumbent firm. Our study also proceeds from the same premise. In contrast, we provide a measure of all acquisitions of patents, measure its importance for all inventive activity, and find it plays only a small role.

Most of the prior literature on the interaction of M&A activity with innovation comes from analyses of public firms, as data on private firms is scarce. Here, again, we contribute by analyzing private firms. The gap in the literature is substantial. Private firms constitute an important part of the US economy: Asker, Farre-Mensa, and Ljungqvist (2012) estimates that private US firms account for 67.1 percent of private sector employment, 57.6 percent of sales, and 20.6 percent 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 exacerbated through acquisition of startup firms, as startup firms are likely to be underrepresented in deals of only public firms. Linking the USPTO patent data to the M&A data enables us to work around this issue and to provide new insights on the behavior of this nontrivial, yet underexplored, part of the US economy.

ICT Equipment Industry Concentration

How should we think about deconcentration of inventive activity in the ICT equipment industry from the late 1970s to the present? ICT equipment is responsible for electronics, computing, and the infrastructure of radio, television, voice, and broadband communication services. It would take several books to describe the changes in market structure during this time, and this section cannot hope to review all the details. The purpose here is only to refresh the reader's memories about what the literature takes for granted about major changes in the concentration of origins of

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

inventive ideas in a wide set of related industries. This will provide just enough of a brief overview to guide our framework for the statistical exercise.

Historical Overview

Prior to the 1980s, the ICT equipment industry consisted of various segments, depending on whether it was oriented towards computing, as it was then understood, or communications, namely, voice or data. Both of these segments were highly concentrated in final goods markets. At the end of the 1970s, IBM dominated the computing segment with its mainframe systems and the components built around those systems. It also dominated the personal computer system market for a short time, growing a small systems division that in 1984 was the third largest computer company on the planet (behind Digital Equipment Corporation and IBM itself).

Starting in the mid-1980s and accelerating thereafter, IBM lost market shares in personal computers and in many of the peripheral markets. After the introduction of the IBM PC in 1981, a wide range of firms entered into printers, software, component production, local area networks, and more. In the 1990s, Microsoft and Intel began to assert control over an increasing fraction of valuable components within the PC market; nonetheless, a large number of firms played a role in many of its segments.

Before the 1980s, AT&T was the dominant provider of networking equipment in the voice segment, largely due to its regulated monopoly position in telecommunication services: approximately 90 percent of AT&T's equipment purchases were supplied from its equipment subsidiary, Western Electric. The voice segment was based on circuit-switching technology and provided the infrastructure mainly for local and long-distance telephone companies. Furthermore, AT&T fought regulations that ended the requirement that any equipment attached to its network be supplied by AT&T, even on the end-user site. The purchase behavior and network attachment requirement of AT&T restricted entry into the telecommunications equipment markets, thus carrying AT&T's dominant position in telecom services into the telecom equipment sector.

AT&T eventually lost most of those fights, which yielded change, but 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. In 1975, the Federal Communications Commission (FCC) extended the Carterfone decision to all private subscriber equipment that is registered to and certified by the FCC. These decisions removed barriers to entry into the telecommunications equipment industry; however, as long as AT&T remained the dominant purchaser of equipment, entry was limited. The market structure changed further with the 1974 US Department of Justice antitrust suit against AT&T. The case was settled in 1982, with AT&T dividing itself into one long distance telephone provider, and seven independent, regional holding companies. That eventually altered equipment purchasing decisions. As a result the telephone markets underwent considerable changes in the early to mid-1990s.[10]

Large growth in demand occurred in the data segment based on packet-switching technology. This segment supplied the communication equipment required in the computing industry, including modems and local area networks. Until the emergence of the Ethernet standard, this segment was characterized by proprietary protocols. Only with widespread use of the Ethernet standard in the late 1980s and the Internet IP stack in the early 1990s did non-proprietary standards begin to shape industry structure.

The networking and Internet revolution of the 1990s blurred the distinction between different segments of ICT equipment (Lee 2007). This process sometimes receives the label "convergence," which means that previously independent product market segments increasingly become substitutes or complements in demand. On the computing side, systems of PCs and workstations were initially hooked together with a local area network (LAN). Over time, client-server systems within large enterprises and across ownership boundaries were established. Novell,

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

3Com, Oracle, and Cisco were among the firms with dominant positions in this era.[11] With widespread Internet use, the scope of ambitions became quite large, touching on virtually every economic activity in which transmission of information played an important role. This period was marked by economic changes to the applications of computing and communications, as well as any related upstream or downstream activity. It was marked by optimism and labeled "the dot-com bubble," in recognition of the many startups that ended with the top-level domain name "com."[12]

In contrast, by the beginning of the millennium, many layers of the industry underwent upheaval. Some of this was associated with large, painful adjustments due to a decline in demand that was linked to the implementation of the 1996 Telecommunications Act, resulting growth, and the Telecom Meltdown. Some of it was due to the bursting of the dot-com bubble. Eventually the equipment market stabilized, leaving Cisco in the dominant position in enterprise computing to serve data communications. Yet other firms who grew spectacularly during the 1990s, such as JDS Uniphase, Corning, Lucent, Nortel, and 3Com, did not fare as well.

This brief review suggests several of the core questions that motivate our statistical work. First, is the evidence consistent with the common understanding of this industry history, that there has been a deconcentration in the ownership of inventive ideas? Second, can this deconcentration be explained by a single event, such as the divestiture of AT&T or the loss of commercial leadership at IBM, Motorola, or any other large industry firm? Third, what role do other factors play, such as firm entry, particularly non-US-firm entry, which has accelerated over this period? Fourth, has the externalization of R&D by established firms merely changed the structure of the origins of invention, but not its concentration as it relates to final output markets?

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[11] See, e.g., Bresnahan and Greenstein (1999).
[12] For a review of the extensive literature on trends and causes, see Greenstein (2010, 2015).

Theoretical Framework

This section provides a brief overview of our framework. It fixes a few key ideas and provides a roadmap for later developments.

Following prior literature (Arora and Gambardella, 2001, Gans, Hsu and Stern, 2002), we divide the industry into an upstream sector that supplies invention and a downstream sector that supplies products. The downstream sector employs inventions from the upstream sector in production.

The literature on the rise of DTL focuses on the increasing infrequency of situations where one firm has a monopoly over an idea. In practice, these ideas come from very specific classes of technologies and map into very specific product markets. The literature stresses that such monopolies are less likely to arise where many technical substitutes can emerge. Substitutes are more likely to emerge in settings where many potential inventors generate similar ideas and where entry into production of ideas is less costly.

We considered a wide range of alternative ways of measuring settings where many potential inventors generate similar ideas. For reasons explained below, we settled on a top-twenty-five concentration ratio over the ownership of inventive ideas, which we label as C25, in technological class, indexed as i. Illustrating the concept, a technological class i is said to be more concentrated if the largest twenty-five firms own 80 percent of the inventive ideas, instead of, say, 50 percent of the ideas in that technology class.

The literature discussed many related measures of concentration for a sector, which are book-ended by two concepts, one related to the *flow of new ideas,* another related to the *stock of ideas that firms own and use*. A firm accumulates ownership of many inventions by accumulating ownership of patents over the active lifetime of patents, which we coin the *patent stock*, which corresponds to the discounted sum of patent flow over the firm's history, less the expired (old) patents.

The existing literature on DTL suggests the flow of ideas is relevant for fostering entry into product markets, for example, while the stock of ideas is relevant for new combinations of technologies fostering entry or industrial change. In this paper we focus on the stock of ideas, though our qualitative results also hold in the flow of ideas, the results of which we provide in Appendix B.

Based on the set of active patents in a given year, we calculate the patent stock by discounting the patents from prior years using the declining balance formula. 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 percent.[13] This depreciation accounts for two known factors: the obsolescence of patents over time as the technology becomes older and irrelevant, and the shorter remaining active time of older patents. Both of these imply a lower value for the patents.[14]

Some of the writing on DTL suggests that many patents are not relevant for entry, and only high-quality patents facilitate entry. The above definition can be modified to focus on the stock and flow of only high quality ideas.15

The first key question concerns changes in the concentration of ownership over time. Is the evidence consistent with decreasing concentration over time? We focused on the question for each i, namely,

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

[13] 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).

[14] 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.

[15] 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.

Generally, we find below that a wide range of technology classes did become more deconcentrated. This motivates the second question, concerning the causes of less or more changes in concentration over time. In general, our approach identifies the causes of the variance in changes of concentration between different technology classes. That is, we posit:

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

The literature on DTL frames the open question: what factors caused changes in concentration? There are various theories on why the changes in concentration arose. We divide these theories into two distinct groups: those concerning the supply and the demand of technology.

As our review of the history suggests, important supply-side factors include the decline of dominant firms, increasing economies of scope across technology sectors, changes in entry costs for small or foreign firms, and the cost of diffusing ideas. Important demand-side factors include the increasing use of mergers by leading firms to obtain invention from external sources, increasing acceptance of technical products from unbranded firms by users, and the increasing use of open standards that permit customers to buy interoperable products from more than one supplier.

We now discuss these factors in detail. We will discuss, and later construct measures for, all supply side factors, while the latter two demand factors will be absorbed into time trends, so we will be able to focus only on the demand for mergers.

On the demand side for inventive ideas we look at the merger market. In studies of invention, patent applications reflect only the invention created by the patent applicant and do not take into account alternative mechanisms of obtaining patents, including acquisition of patents or acquisition of other patent assignees. 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.[16] We consider the acquisition of patents through acquisition of other patent assignees a source of demand for invention and 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.

The location of the inventive activity constitutes a supply side factor in deconcentration. Metropolitan areas may provide an ecosystem that nurtures small firms, providing smaller entities with access to a highly-skilled work force and an ecosystem of complementary services within which to thrive.[17] Such an ecosystem may result in metropolitan areas substituting for large, established firms, hence enabling outsourcing of invention. Alternatively, a high geographic concentration of patent origins may be indicative of high entry costs or fewer sources for diffusing the underlying know-how, leading to concentration of economic activity in a smaller set of urban areas. The former would result in a decrease in concentration of ownership while latter would result in an increase in the concentration of ownership. We consider this an empirical question.

Firm entry into innovative activities is another supply side factor that provides a theory of deconcentration (Hall, 2005, and Kortum and Lerner, 1999, among others). In our framework, firm entry captures the level of 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-US firms.

In addition to firms entering into the ICT equipment industry from outside, firms may also be active in one ICT equipment class and later move to a new ICT equipment class. We consider such firms lateral entrants. We theorize that a higher lateral entry level implies higher economies of scope across different technology classes. If the firm conducting the lateral entry is larger than

[16] See Ahuja and Katila (2001) and Cassiman and Valentini (2016), for open innovation, and Ozcan (2016) for transfer of invention through M&A activity.
[17] See Chang and Wu (2014) for a discussion of the role of agglomeration on entrant costs.

the firms in its new technology area, then lateral entry would reduce concentration, and vice versa. Therefore, the impact of lateral entry on concentration of ownership is an empirical question.

The final supply-side factor we consider is product market leadership. Product markets constitute the downstream for innovation markets, and a fragmented product market is more conducive to the commercialization of the upstream invention (Gambardella and Giarratana 2013). We theorize that a more concentrated product market, with few firms leading, would result in less entry into upstream inventive activity due to the lower probability of success in commercialization. This is further strengthened by the conventional wisdom that the breakdown of AT&T caused the deconcentration in patent ownership. We lack data on the links between patent technology classes and product market classification, therefore, instead of using product market concentration measures, we use the presence of a big firm in an attempt to proxy product market leadership.

Data

Patents are one of the most utilized sources of information in the innovation literature. The use of patent data as a proxy for inventive activity dates back to Schmookler (1951) and Griliches (1990). Since then, an extensive literature on using patents as indicators of innovative activity has developed.[18] Here we follow this literature and focus on patents granted in the ICT equipment industry as a proxy for the origins of innovative activity. Since pursuing questions related to DTL led us to modify the practices underlying existing patent datasets widely in use, we first devote space to explaining our overlap with and departures from the existing literature. We then establish changes in the level of ownership composition of new and cumulative innovative activity, and then link these changes to underlying supply- and demand-side factors. Supply-side factors include new entry, lateral entry (a firm's economies of scope), and growth; the demand-side factor we utilize is the M&A activity of established firms.

[18] See, e.g., Griliches (1990) and Nagaoka, Motohashi, and Goto (2010).

The standard source for patent data has been the NBER patent data files. However, we use raw USPTO files to construct updated patent data files and to enable linkage between the patent data and the M&A data. Appendices A and B 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. We then drop fourteen classes due to sparse patenting activity. 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 percent of patents account for as much as 80 percent 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 examined the entire sample of patents and the top decile of patents, without any large change in inference. Appendix C reports these results. We use M&A activity as a measure of the demand 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 US 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 eliminate deals that are not of interest. The final sample has 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.[19] However, comparison with Serrano (2010) leads us to believe that a merger is a very good proxy for demand. Serrano records that 13.5

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

percent 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 percent (11/13.5 > .8) of the transfers in ownership of patents measured by Serrano occur due to M&A.

Concentration and Other Measures

In this section we describe the market structure, technology supply, and technology demand proxies we use in our empirical framework.[20]

Our main variable is the patent ownership concentration in a technology class. We capture the ownership 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-year bucket and 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 of the technology class-year buckets, the top twenty-five firms reach 100 percent ownership in the early years of our sample. On average the top twenty-five firms in a technology class-year bucket own 55 percent of high quality patents. However, as we discuss in the next section, there is considerable variation in this concentration over time.[21]

In analyzing the changes in concentration, we construct variables to capture demand-side and supply-side factors. On the demand side, we use merger intensity, and on the supply side, we use geographic concentration, new firm entry, lateral firm entry, and product market leadership. We now provide details of each measure.

[20] Table 3 provides a summary of these variables.

[21] In this context, more general measures of concentration, including Gini coefficients and 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.

A source of demand for invention is the acquisition of patents through acquisition of other patent assignees. In our theoretical framework, a 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 percent of existing high-quality patent stock is transferred through M&A activity (Table 3), with considerable variation across different technology sectors. Though this may seem small on the surface, it is not in practice. We will show that around 12 percent of high quality patents change hands through the merger and acquisition of patent assignees. In our theoretical framework, the higher merger intensity is indicative of a lower cost of absorbing ideas from acquired firms.

The location of inventive activity is another supply side factor we consider. 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 ownership is indicative of high entry costs, than we expect the *Top 10 MSA Share* to have an increasing impact on patent ownership concentration.

In an effort to capture the impact of firm entry, we have three classes of entry variables. In the first class, patent-weighted entry level, we construct two measures of entry based on the previous patenting activity of the firm: *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 percent of the patents stock in a technology class.[22]

Another supply-side factor is economies of scope, which we capture with lateral entry of firms from one technology sector to another. 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 percent of high quality patents come from lateral entrants.

Taking into account that the entry of a firm may not fully materialize within one year, we also construct entry variables with a four-year time window, in which we consider any entry over the previous period 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%.[23]

The two entry variables, *new entry share* and *lateral entry share,* proxy for patent-count weighted entry into a technology. 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 percent new entry and 2.7 percent lateral entry averages, we deduce that on average 93.6 percent (100-3.7-2.7) of patents come from firms that already had patents in

[22] 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 an entrant in the first period it produces a high-quality patent.
[23] The dramatic increase in new entry share is by construction. In the 1-year measure the patent stock from only the entry year is considered, whereas in the 4-year measure each firms' 4-year patent stock is included.

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. Using simple firm counts, we calculate the growth in the number of firms over time. We see that on average the number of firms has increased by 9 percent every year for both the US and foreign firms.

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

The final class of control variables in our model consists of proxies for an increase or decrease in product market leadership: dummies for the presence of a big firm. Conventional wisdom that the breakdown of AT&T caused the deconcentration in patent ownership calls for these controls. In an attempt to discern whether the existence of big firms, namely AT&T, Motorola, and IBM, have an impact on the concentration, 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 five patent applicants in 54 percent of technology class-year cells, whereas AT&T and Motorola are in the top five patent applicants in only 41 and 32 percent of the cells, respectively.

Deconcentration of Patent Ownership

Historical trends

We begin by presenting the broad changes in the distribution of ownership shares over our sample period. At the head of the ownership distribution, the number of firms that has more than

5% of shares in any technology class drops from 66 in 1986 to 60 and then to 47 in 1996 and 2006, respectively.[24] The question is then on where this drop is shifting to, to the middle or the tail of the size distribution. Figure 1 presents these trends for the firms that have less than 5% ownership share. In Panel A, we observe that the number of firms that have between 0.5% to 5% share also drops from 1986 to the following decades, and this drop is also exhibited for firms that has 0.35% or higher share in Panel B. On the other hand, we see a secular increase in the very small end of the distribution: the number of firms that has less than 0.15% of patent stock share increases from 1986 to 1996, and then again from 1996 to 2006. For the 0.15% to 0.35% ownership share range, the increase happens between 1986 to 1996, but then there is a reduction in the following decade. These results suggest that the top firms (along with the mid-size firms having more than 0.35% ownership share) lose patent stock ownership share to the very small end of the firm size distribution over the last two decades.

When we take a closer look at the historical ownership trends. Figure 2 includes the ten firms that appeared the most within "the top 5" ofeach technology class during 2006 and 2007. Panel A includes firms that maintain or lose its position while Panel B constitutes firms that are becoming more prominent over decades. Between 1986 and 1990, IBM is among the top 5 firms in 17 of the 30 technology classes on average. Over the years this leadership position remains relatively stable, declining from 17 to 15 classes on average. Texas Instruments is another firm that remains relatively stable in its leadership position. On the other hand, AT&T, Motorola and Hitachi all go through a dramatic decline. Firms that are increasing in their frequency of top-5 appearance include new firms as Microsoft and Intel, and foreign firms as Sony and Samsung. In 1980s four firms appeared among top 5 in more than 10 technology classes. However, despite the

[24] 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.

rapid increase in the emerging leaders, only IBM appears in more than 10 classes as a leader. All other firms appear in less than 10 classes, suggesting a decrease in the strength of leadership of firms in this ecosystem.

We now focus on capturing these leadership dynamics in a broader sense by characterizing these long term trends in our endogenous variable. We construct and analyze a measure of concentration across the thirty ICT equipment technology classes. To capture the dynamics of patent ownership, we calculate the *patent stock* variable—the number of active patents a firm has been granted since 1976 absent expired patents.[25]

We use $C25_{stock}$, the share of top twenty-five firms in patent stock, as our measure of concentration. We discuss this choice of the concentration measure further in Concentration and Other Measures Section.

Figure 3 illustrates the CX_{stock} values for technology class 385 (Optical Waveguides). The top line in Figure 3 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 percent in 1976 to 39 percent in 2007. In fact, we observe a similar trend in twenty-nine of the thirty classes in our sample of high quality patents. The values of $C25_{stock}$ fluctuates in only one class. All these trends suggest a deconcentration of ownership in patents in our sample period.

We now turn to Table 1 to observe this deconcentration trend across all technology classes. Table 1 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

[25] 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 closed 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.

share across technology classes follows a gradual decline over the years from 65 percent in 1986 to 51 percent in 2007.

We now investigate potential causes of this deconcentration across technology classes. Industry insiders attribute this deconcentration to the breakdown of AT&T in 1982 during the deregulation of the telecommunications industry. To see if this claim holds in a first pass through the data, we calculate a simple statistic, the number of firms that contribute 90 percent or more of the changes in $C25_{stock}$, the share of top twenty-five firms, over our sample period. The results are presented in Table 2, 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 percent or more of the reduction in $C25_{stock}$. In the remaining 23 classes there is an industry-wide deconcentration trend, which suggests that the breakdown 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.

Role of acquisitions

We have shown that the top twenty-five firms in the ICT equipment industry hold a smaller share of the patent stock than they did two decades ago. However, these analyses consider only the in-house production of patents and do not take into account the patents acquired through alternative mechanisms, including acquisition of innovative firms. We see tremendous number of acquisitions taking place in the ICT equipment industry, and the impact of the transfer of patents through acquisitions on concentration depends on the status of the target and the acquirer. In cases in which the buyer is simply supplementing its existing portfolio of patents by acquiring a target active in the same technology class, then ownership becomes more concentrated. However, if the acquirer is simply entering a new technology class by acquiring a target active in that technology class, then the ownership concentration does not change in that technology class.

We resort to the M&A data to proxy for the demand 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. Please note that transfers of patents take place in approximately one out of seven (3,008 out of 19,878) M&A deals involving ICT equipment patent holders (See Appendix A4, and Table A3).

The sheer ratio of M&A deals with patent transfers may not translate into a large number of patents if the target firms possess only a few patents. To assess the share of patents transferred through M&A, we report the patent stock for the ICT equipment industry and for the firms that were targeted in an M&A deal in Table 5. We calculate the patent stock using the declining balance formula as described above. The total 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. For the purposes of Table 5 we similarly calculate the patent stock of target firms. Note that, unlike earlier sections, which considered the patents of only the top twenty-five firms, Table 5 reports patents acquired by all firms.

In Table 5 we observe that the stock of patents that changed hands through M&A transactions increase 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 percent in the early 1980s to 12 percent in 2007. This observation holds for both the entire sample and high quality patents, with a share of the transfers 2 percent 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 percent of the acquirer patent stock, which decreases to 19 percent in 2007. We see a similar trend with a slightly lower transfer ratio in the entire patent sample.

The transfer of 12 percent of an industry's patents through M&A activity is a significant source of ownership change. However, we can compare the 14 percent approximate decrease in the ownership share of the top twenty-five firms in cumulative patent stock to the 12 percent 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 an interesting open question. Looking at how new entry and lateral entry vary over time (averaged across technology classes), we observe a declining trend in both. The new entry share starts around 5 percent in 1986 and gradually drops to 1 percent in 2007. The lateral entry share follows a similar declining trend, with 3.4 percent in 1986, and 0.7 percent 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.

Composition of ownership: the model

Having established historical trends of patent stock ownership, we now turn our attention to combining demand-side and supply-side explanations in a fixed effects model. Table 3 presents the summary statistics used in the patent stock model. These variables are constructed in the same way as described for the flow analyses above, with the difference that we now use the depreciated stock of active patents instead of the flow of new patents. Keep in mind that the period for these patent stock analyses is a single year, as opposed to the two-year period in the flow section above. In light of this information, we see that the number of firms grows at a pace of 9 percent each year and the number of patents grows at 10 percent.

As expected, recycling patents over their lifetime results in a lower new entry and lateral entry share: each year, 3.7 percent of the patents in a technology class belongs to new entrants, and another 2.7 percent belongs to lateral entrants. This implies that each year roughly 94 percent 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 percent per year, and lateral entry increases to 7.7 percent. The positions of IBM and Motorola appear slightly stronger in the patent stock than in the patent flow due to the cumulative impact of their prior patents, whereas AT&T remains roughly at the same position.

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 *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 on 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: growth in US-based firms and patents and 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.

We present the fixed effects model of patent stocks in Table 4. The dependent variable in the model is $C25_{stock}$, the share of top twenty-five firms in cumulative patent stock up to the period of observation (indexed by t). All models include class and time fixed effects.[26] We clustered the standard errors by technology class.[27] 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 4 reports the coefficient estimates of the time fixed effects from the model, which indicate a secular deconcentration over the years. On average, the concentration of a technology-class in a year-group is 8.12 percent (=-9.61%-(-1.49%)) lower in 2007 than in 1987. In discussing the impact of other covariates below, we will occasionally compare the impact induced to this time impact of 8.12 percent to gauge a relative sense.

As our demand-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, implying that demand for ideas does not have a big impact on the concentration of ownership.[28]

On the supply side, the impact of top ten MSA share is also both statistically and economically significant across specifications for the high quality patents. An average level of top ten MSA share, 50 percent, results in increased concentration of 15.57 percent (=0.50 * 0.31), which is almost twice the magnitude of the deconcentration induced by time (8.12%). This results holds both for the top quartile and top decile patent samples; however, in the entire sample of patents, the share of top ten MSAs does not have a statistically significant impact on concentration. This suggests that the forces that limit geographic diffusion of ideas are more prevalent in the geographic concentration of patent ownership than the replacement of large firms by metropolitan areas.

[26] In unreported results we use a linear and a quadratic time trend instead of time fixed effects. The qualitative results remain the same in these alternative specifications.
[27] Two-way clustering of the standard errors by class and time does not change our statistical inferences.
[28] 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 results on new entry, which is a proxy for the patent-weighted entry of firms that were not active in ICT equipment previously, are mixed for the one-year entry window, but are quite 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 percent entry (the average level) results in a 0.8 percent (=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. On the other hand, new entry every four years is both statistically and economically significant. The average four-year new entry of 26 percent results in a 8.4 percent (=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 fixed-effect captures the cumulative one-time impact.

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

The lateral entry, our proxy for economies of scope, is associated with an increase in the ownership of top firms, though the impact loses its statistical significance in some models. A technology class experiencing the average level of lateral entry, 2.7 percent per period, faces a 2.07 percent (=0.76 * 0.027) increase in $C25_{stock}$. This result may be driven by the fact that firms conducting lateral entry operate in multiple segments of the industry, hence they are expected to have a bigger operation than others, and the loss 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 have high-quality patents previously; 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 coefficient of the IBM indicator is also not significant. The presence of Motorola as a prior top-five patent applier, however, is associated with an approximately 2.7 percent increase in the ownership concentration of the patent class over two years. A detailed look at Motorola's activity reveals that it focuses on five technology classes in which the deconcentration is less than the average across all technology classes. We cannot say whether the increased concentration is caused by the presence of Motorola in these technology areas or whether Motorola selected to invent in areas with this feature.

The main results across all models show that growth in the new firm shares, and the number of firms are important drivers of deconcentration, suggesting that a smaller transaction cost for entry results in lower ownership concentration. Lateral entry and Top 10 MSA Share work in the opposite direction of entry by increasing the concentration of patent ownership. 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 ten MSA share increases.

Based on these results, one may ask what causes entry into new inventive areas by firms who previously have 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. This question constitutes the next step in analyzing the innovation markets and must be left for future work.

Conclusion

In this article we characterize long-term trends related to the concentration of the origins of inventive ideas in the ICT equipment industry. 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 the deconcentration arises in every measure of the trend. It 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.

We analyze evidence about the causes of this change. The statistical evidence is consistent with explanations that stress the role of supply-side changes more than demand-side changes. We present evidence that firm entry accounts for part of this deconcentration. Importantly, we reject the notion that non-US-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.

The deconcentration of ownership results we obtain relate to the literature on Divided Technical Leadership (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 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, hence higher levels of inventive activity under a model where incentives increase monotonically with greater competition.

Finally, this 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 Industry. First, we showed that there is a considerable transfer of patents through M&A, which relate 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.

The study has several inherent limitations. The USPTO classification system we used constitutes a limitation. Though no single technology class dominates our data, the definition of these classes may depend on industry developments, which may have ramifications for our analyses. In addition, our data includes patents granted since 1976. This restriction truncates the patent stock variable for the early years of our sample, as we do not have information on active patents before 1976. Though the history of (de)concentration in electronics goes back much further in history, these data limitations prevent investigation of the earlier trends and causes.

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Table 1: Distribution of $C25_{stock}$ values

Year Group	Mean (%)	St. Dev. (%)	10%	25%	50%	75%	90%
1986	65	17	43	56	63	75	89
1987	63	16	42	56	59	75	87
1988	61	15	41	53	60	72	84
1989	60	14	41	53	59	69	82
1990	59	14	41	54	58	67	78
1991	59	13	39	53	59	70	78
1992	58	12	38	52	58	67	72
1993	58	13	36	52	57	67	72
1994	57	12	36	51	57	66	70
1995	56	12	35	51	57	63	69
1996	55	12	34	51	57	60	70
1997	54	12	34	50	56	60	69
1998	54	11	34	50	55	59	67
1999	53	11	32	48	54	59	66
2000	52	11	31	47	54	58	65
2001	51	11	31	46	53	57	64
2002	50	11	32	44	52	56	64
2003	50	11	32	44	52	56	63
2004	50	12	32	44	52	55	64
2005	51	12	33	45	52	56	65
2006	51	12	34	45	52	56	65
2007	51	11	34	44	52	56	65

Notes: Evolution of the patent application *stock* share for top twenty-five firms. Each row corresponds to a calendar year. 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.

Table 2: 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 3: 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. HHI refers to the Herfindahl–Hirschman Index 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 4: OLS analysis of patent *stock* ownership concentration

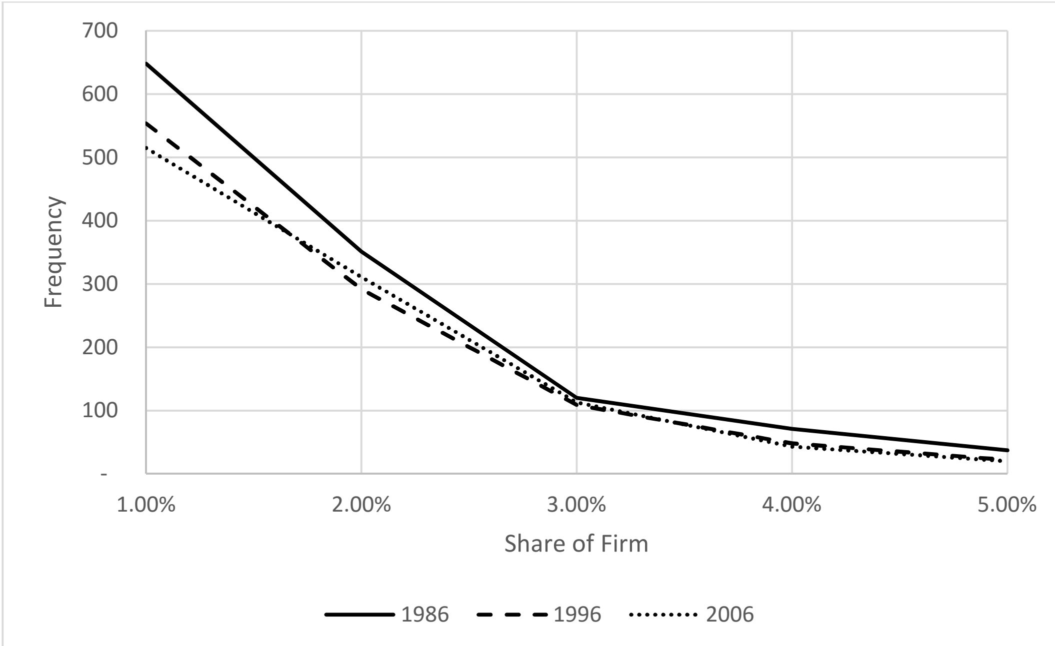
Dependent Variable: $C25_{stock}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
M&A Intensity (No of patents	-1.11	1.17	-0.82	1.04	-0.24	1.46	4.14	4.18
transferred in M&A / All Telecom)	(11.18)	(10.57)	(12.59)	(12.20)	(10.03)	(9.69)	(10.94)	(10.73)
Location Top 10 MSAs	31.14	31.18	35.27	34.91	36.44	37.02	36.62	37.63
	(9.96)***	(9.98)***	(10.26)***	(10.23)***	(12.96)***	(12.93)***	(12.80)***	(12.72)***
New Entry Share (1 year)	68.39	59.48	21.59	15.52				
	(33.03)**	(32.83)*	(33.87)	(33.45)				
(4 years)					-32.42	-32.86	-37.44	-37.20
					(8.93)***	(8.61)***	(8.11)***	(8.16)***
Lateral Entry Share (1 year)	76.79	77.21	41.39	41.47				
	(33.88)**	(36.32)**	(38.35)	(40.35)				
(4 years)					1.69	2.07	-4.77	-4.37
					(4.66)	(4.36)	(5.56)	(5.49)
Total Growth in No of Firms	-50.01				-5.25			
	(11.65)***				(7.78)			
US only		-29.29				3.72		
		(8.95)***				(5.68)		
Foreign only		-17.43				-8.91		
		(4.23)***				(3.46)**		
Total Growth in No of Patents			-11.56				6.53	
			(7.07)				(5.17)	
US only				-4.12				8.27
				(4.40)				(3.78)**
Foreign only				-4.81				-1.22
				(2.86)				(2.30)
Lagged Dummies if Firm is in Top 5								
AT&T	-0.86	-1.01	-1.01	-0.95	-1.23	-1.39	-1.20	-1.16
	(0.97)	(0.96)	(1.03)	(1.02)	(0.94)	(0.94)	(0.97)	(0.95)
Motorola	-1.60	-1.58	-1.33	-1.37	-1.45	-1.47	-1.40	-1.47
	(0.91)*	(0.91)*	(0.97)	(0.97)	(0.89)	(0.88)	(0.89)	(0.89)
IBM	-1.52	-1.51	-1.65	-1.63	-1.63	-1.64	-1.57	-1.48
	(1.34)	(1.32)	(1.54)	(1.52)	(1.61)	(1.55)	(1.63)	(1.59)
Intercept	47.68	47.42	44.07	44.32	77.87	77.74	81.32	80.51
	(5.73)***	(5.68)***	(5.22)***	(5.24)***	(8.70)***	(8.54)***	(8.44)***	(8.00)***
N	660	660	660	660	660	660	660	660
Number of Classes	30	30	30	30	30	30	30	30
R-Squared	0.61	0.62	0.58	0.58	0.61	0.62	0.62	0.62

Notes: Regressions are ordinary least squares, 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. Models 1-4 include a linear and a quadratic time trend; models 5-8 include 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.

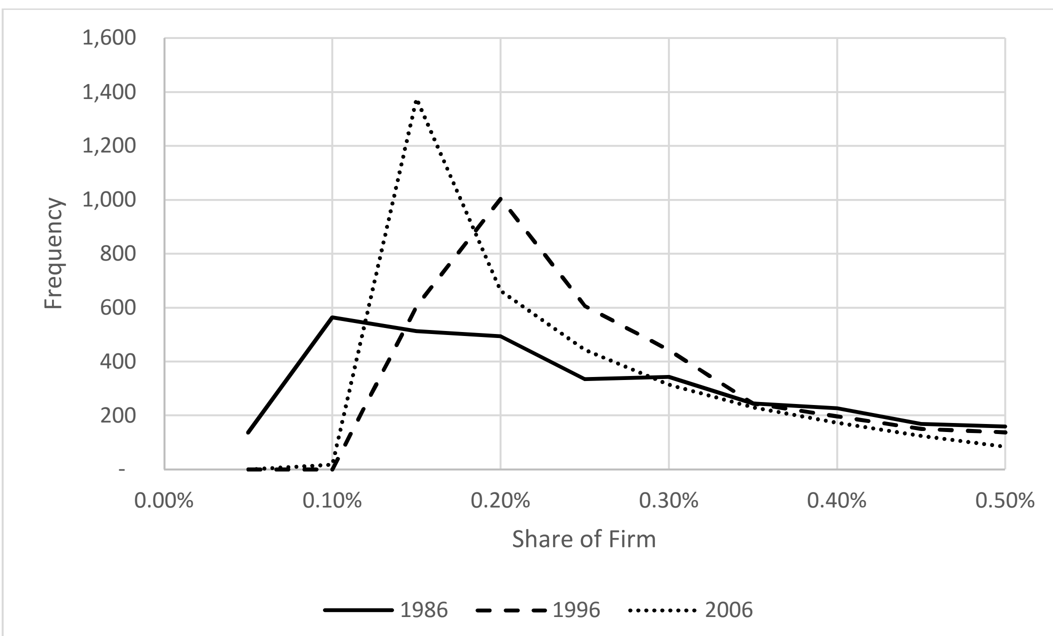
Table 5: Cumulative ICT equipment patent stock

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.



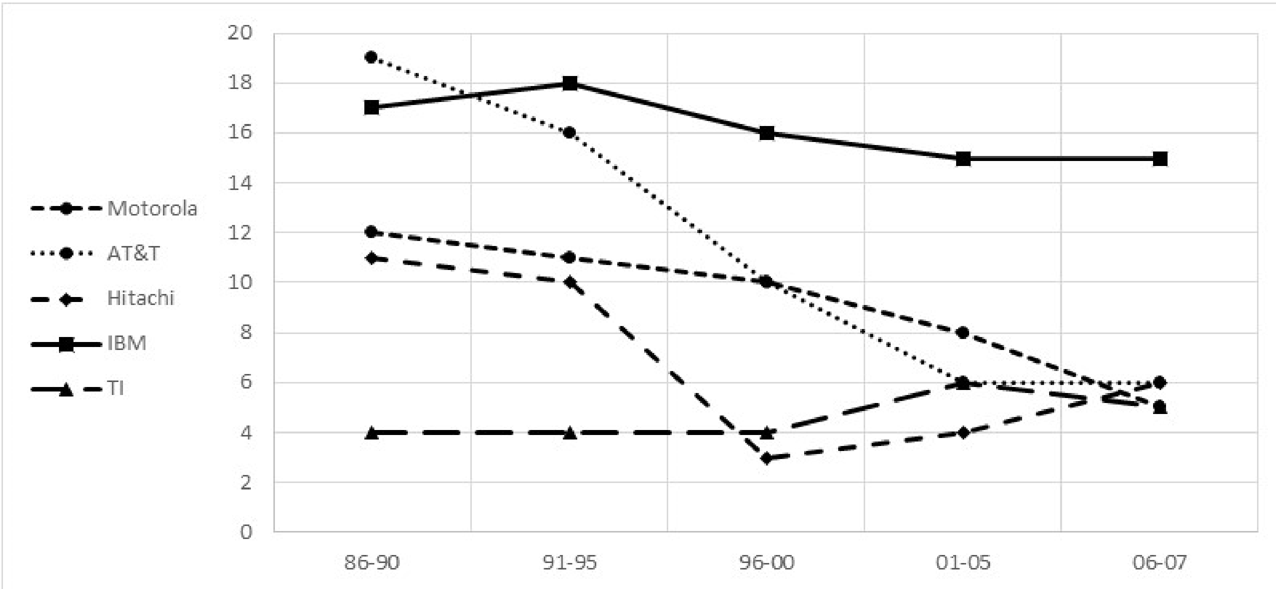
Panel A



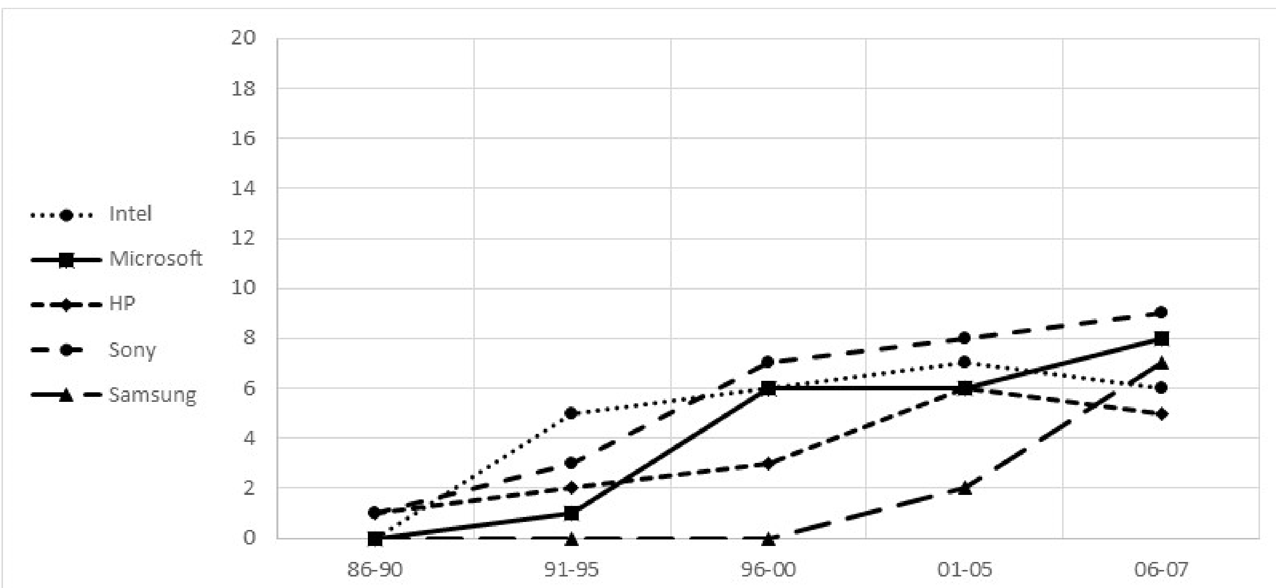
Panel B

Figure 1: Histogram of Firm Ownership Shares

Notes: 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. Panel A presents the frequencies for the 1% to 5% range, while panel B presents for shares less than 1%.



Panel A



Panel B

Figure 2: Historical Leadership Positions of Top 10 Firms

Notes: 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 5 firms in a patent class within a year in holding the top quartile of patent stock. The figure presents leadership counts averaged over five year periods. The patent stock is the discounted sum of unexpired patents. Panel A presents firms that maintain their position or decrease in leadership strength. Panel B presents firms that are gaining more prominence.

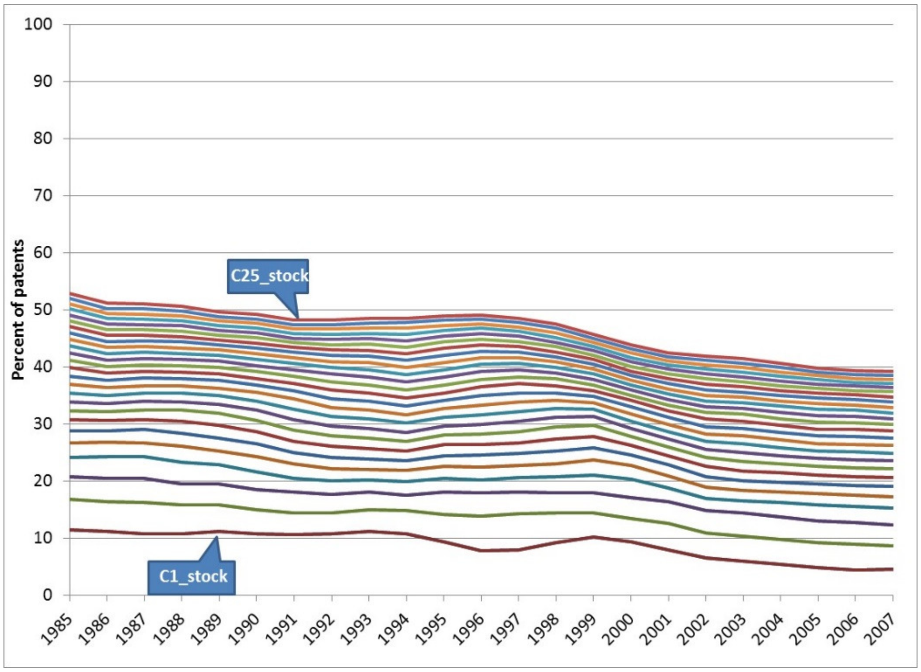


Figure 3: Patent Stock Concentration Levels (Technology Class 385)

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.

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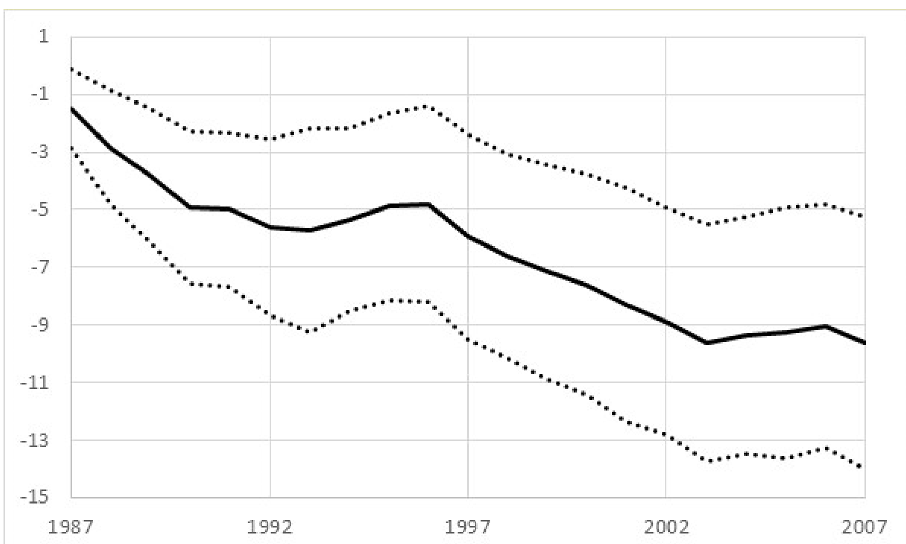

Figure 4: Patent stock – time fixed effects coefficient estimates

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.