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TECHNOLOGICAL LEADERSHIP (DE)CONCENTRATION:  
CAUSES IN ICTE

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Technological Leadership (de)Concentration: Causes in ICTE  
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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.

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An online appendix is available at <http://www.nber.org/data-appendix/w22631>

## Introduction

The market structure for the Information and Communications Technology (ICT) equipment industry has undergone enormous changes in the last four decades. Thirty years ago, most innovation took place in established firms, in particular 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 high rates of firm entry and exit 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). It also 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). DTL contributes to a market structure in which a dispersed set of market participants produces a range of new innovative prototypes for potential acquisition. 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, measuring the contribution of economies of scope, product market leadership, entry by domestic and foreign firms, and changes in demand for ideas from 1976 to 2010.

To construct measures of the origins of innovation, 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.<sup>1</sup> 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 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

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<sup>1</sup> For details on the NBER patent data files, see Hall, Jaffe, and Trajtenberg (2001).

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 DTL. We find a trend in deconcentration, both in the ownership of new patent applications and also 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 72 percent of new patents in 1976 and 59 percent of the patent stock in 1986, the top twenty-five firms accounted for only 55 percent of new patents and 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 86 to 62 percent in new patents and 65 to 51 percent in the patent stock over the same period.

Why does this deconcentration arise? On the supply side, one hypothesis stresses that large firms may utilize economies of scope by entering other technologies, which may appear as increased or decreased concentration, depending on the size of the entry.<sup>2</sup> 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 larger fraction of imports and exports in the US economy over this period).<sup>3</sup> Rather, established changes in concentration may come from two distinct areas of the ownership

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<sup>2</sup> For economies of scope in technology see e.g. Chen, Williams, and Agarwal (2012), Leiponen and Helfat (2010), and Miller (2006).

<sup>3</sup> 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.

distribution: 1) declines in the leading, large firms and 2) an increase of innovation 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, that the decline in the importance of the very largest firms merely reflects a decline in their importance in downstream markets.<sup>4</sup> 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.

Finally, the study looks at the demand for inventive ideas by examining the merger market. 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.<sup>5</sup> 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 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

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<sup>4</sup> See Miller (2006) for the relation between technology and product markets of firms.

<sup>5</sup> See Ahuja and Katila (2001) and Cassiman and Valentini (2016) for open innovation.

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

### **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 innovative activities. Following this literature,<sup>6</sup> 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. 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 innovation 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.<sup>7</sup> 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.

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

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<sup>6</sup> Greenstein, 2010 and 2015 review the literature on computing and commercial Internet, in particular.

<sup>7</sup> See e.g. Mauri and Michaels (1998), Hashai (2015), and Misangyi *et al.* (2006)

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.<sup>8</sup> We expect this bias to be exacerbated in the study of innovation 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.

Finally, we draw on prior work by Ozcan and Greenstein (2013), which examines the flow of new patents in communications equipment markets. Both papers are motivated by a similar set of concerns, stressing the importance of long term deconcentration of invention. The scope of the prior work was quite narrow, however, offering a prototype of investigative approach and stressing the implications for legal researchers of patents. This paper, in contrast, examines a wider set of markets, develops new information on (accumulated) stocks and (yearly) flows of new inventions, expands the number and range of economic hypotheses examined (with a larger set of exogenous variables), identifies and considers a range of robustness tests, and, accordingly, comes to a much richer set of conclusions about the economic causes and non-causes of changes in DTL in the high technology economy.

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<sup>8</sup> See Netter, Stegemoller, and Wintoki (2011) for a detailed discussion of potential biases of M&A filtering criteria.

## **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 inventive ideas in a wide set of related industries. This will provide just enough of a brief overview to guide the development of a 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.<sup>9</sup>

The data segment was based on packet-switching technology and 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

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<sup>9</sup> See, e.g., Crandall and Waverman (1995) for a detailed discussion.

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, 3Com, Oracle, and Cisco were among the firms with dominant positions in this era.<sup>10</sup> 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.”<sup>11</sup>

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.

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<sup>10</sup> See, e.g., Bresnahan and Greenstein (1999).

<sup>11</sup> For a review of the extensive literature on trends and causes, see Greenstein (2010, 2015).

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 something straightforward, 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?

## **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*. 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. Hence, we consider both.

Flow and stock of ideas in technology class  $i$  are related to one another. The stock in sector  $i$  in time  $t$  is:

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

where  $\delta$  is a discount rate for old inventive ideas, and flow is the total available new ideas in sector  $i$  in a given year. 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.<sup>12</sup>

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,

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

Generally, we find below that a wide range of technology classes did become more deconcentrated. This motivates the second question, concerning the causes of changes in

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<sup>12</sup> 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.

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:

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

The literature on DTL frames the open question: what factors caused changes in concentration? As our review of the history suggests, important supply-side factors include the decline of dominant firms, increasing economies of scope across technology sectors, the entry of foreign firms, and the entry of small firms. 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 will construct measures for all three supply factors, while the latter two demand factors will be absorbed into time trends, so we will be able to measure only the demand for mergers.

## 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.<sup>13</sup> 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.

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<sup>13</sup> See, e.g., Griliches (1990) and Nagaoka, Motohashi, and Goto (2010).

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.

The standard source for patent data in the innovation literature 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.<sup>14</sup> However, comparison with Serrano (2010) leads us to believe that a merger is a very good proxy for demand. Serrano records that 13.5 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.<sup>15</sup>

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  $C1_{flow}$ ,  $C2_{flow}$ , ...,  $C25_{flow}$ , where  $CX_{flow}$  is the share of patents applied for by the top X firms within the technology class-year group. In each year group 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  $C25_{flow}$  because in many of the technology class-year groups, 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 group own 68 percent of high quality patents. However, as we discuss in the next section, there is considerable variation in this concentration over time.<sup>16</sup>

There are various theories on why the changes in concentration arose. We divide these theories into two distinct groups: those concerning the demand and the supply of technology. In acquisition of invention, patent applications reflect only the invention created by the patent

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<sup>14</sup> See Arora and Gambardella (2010) and Serrano (2010).

<sup>15</sup> Table B1 in the Appendix provides a summary of these variables.

<sup>16</sup> 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.

applicant and do not take into account alternative mechanisms of obtaining patents, including acquisition of patents or acquisition of other patent assignees. We consider the acquisition of patents through acquisition of other patent assignees a source of demand for innovation and 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. In our theoretical setting, a higher *Merger Intensity* implies a lower transaction cost of absorbing ideas from small firms. On average, each year around 1.1 percent of existing high-quality patent stock is transferred through M&A activity (Table 5), 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.

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.<sup>17</sup> Such an ecosystem may result in metropolitan areas substituting for large, established firms, hence enabling outsourcing of invention. Alternatively, *Top 10 MSA Share*, the ratio of patents originating from the top ten Metropolitan Statistical Areas (MSAs) 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 latter would result in an increase in the concentration of ownership. We consider this an empirical question.

Firm entry into innovative activities provides one theory on deconcentration (Hall, 2005, and Kortum and Lerner, 1999, among others). 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

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<sup>17</sup> See Chang and Wu (2014) for a discussion of the role of agglomeration on entrant costs.

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  $t$ . The new entry variable then captures the level of transaction costs of entry into the market for ideas. When we restrict the variable to account for only foreign entry, we then capture the transaction costs of entry by non-US firms. Firms that have no prior ICT equipment innovation activity produce, on average, 19 percent of patents in a technology class.<sup>18</sup>

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. 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  $j$ . We theorize that a higher lateral entry level implies higher economies of scope across different technology classes. On average 15 percent of high quality patents come from lateral entrants.<sup>19</sup>

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<sup>18</sup> 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.

<sup>19</sup> 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 19% to 30%, whereas lateral entry share remains relatively constant, increasing from 15% to 16%.

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 19 percent new entry and 15 percent lateral entry averages, we deduce that on average 66 percent (100-19-15) 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. 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 15 percent every two years, with firms located outside the United States having a relatively higher growth rate of 22 percent. As an overwhelming majority of the firms in the sample are US-based, the total growth in the number of firms is very close to the growth in US-firms, which is around 14 percent.

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 20 percent every two years (19% in domestic and 30% in foreign firms). When we take into account the 15 percent average increase in the number of firms over two-year periods, which is considerably less than the 20 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 49 percent of technology class-year group cells, whereas AT&T and Motorola are in the top five patent applicants in only 42 and 29 percent of the cells, respectively.<sup>20</sup>

## Deconcentration of Patent Ownership

### Composition of ownership in new patents: historical trends

We begin by describing long-term trends, which characterize our endogenous variable. We construct a measure of concentration and then analyze the new patent creation across the thirty ICT equipment technology classes. To capture the dynamics of new patent creation, we calculate the *patent flow* variable—the number of new patents a firm has applied for in a given year and was granted at a later date.<sup>21</sup>

To ensure that we have enough observation of each patent class during each period in our analyses of patent flow, we use two-year intervals as the measure of time, instead of individual years. Therefore, the observation level throughout the patent flow analyses is a technology class-year group.

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

Figure 1 illustrates the  $CX_{flow}$  values for technology class 385 (Optical Waveguides). The top line in Figure 1 represents the share of top twenty-five firms in the class ( $C25_{flow}$ ), and the bottom line represents the share of the top firm only ( $C1_{flow}$ ). The share of the top twenty-

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<sup>20</sup> These cells correspond to two-year periods as opposed to one year, as discussed in the Deconcentration of patent ownership section.

<sup>21</sup> 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 innovation/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.

five firms has seen a decline from around 70 percent from 1976 to 1977 to around 41 percent from 2006 to 2007. In fact, we observe a similar trend in twenty-seven of the thirty classes in our sample of high quality patents. The values of  $C25_{flow}$  fluctuates in only four classes. All these trends suggest a deconcentration of ownership in new 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  $C25_{flow}$  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 share across technology classes follows a gradual decline over the years from 86 percent in the 1976 to 1977 period to 62 percent from 2006 to 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  $C25_{flow}$ , 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 twenty-seven classes with deconcentration, in only three classes are three or fewer firms responsible for 90 percent or more of the reduction in  $C25_{flow}$ . In the remaining twenty-four 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.

In Appendix B, we analyze these questions in a fixed effects model to provide a coherent framework. The main results show that for the high quality firms growth in the number of firms is an important driver 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, but the patent growth loses both economic and statistical significance.

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 23 percent in 1978 to 1979 and gradually drops to 10 percent in 2006 to 2007. The lateral entry share follows a similar declining trend, with 32 percent in 1978 to 1979, and 8 percent in 2006 to 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.

### **Patent ownership variables: patent flow and patent stock**

In earlier sections we presented historical trends of ownership composition of innovation in the ICT equipment industry, using the flow of granted patents of a firm as a measure of its innovative activity in a given year. However, a firm accumulates ownership of many inventions by accumulating ownership of patents over the active lifetime of patents. We now turn our attention to this historical stock of patents and calculate a proxy for all the patents a firm has created that are still active—the discounted sum of patent flow over the firm’s history, less the expired (old) patents, called *the patent stock*. 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. Based on the set of active patents in a given year, we then 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,  $\delta$ , of 15 percent.<sup>22</sup> 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.

The stock variable depends on the history of patenting activity; therefore, we allow for the variable to accumulate for the first ten years of our sample period and start our analyses of the patent stock in 1986. In other words, our sample for the patent stock section reduces to those in the 1986 to 2007 period.

A second difference between the patent flow and patent stocks is the leadership dynamics: an entrant may obtain a leadership position in patent flow relatively quickly by producing more than its competitors in a given period, as there is no dependence on past activity. However, assuming a leadership position in patent stocks may take longer due to the accumulated patent stock of incumbents over prior decades.

### **Composition of ownership in cumulative patent stock**

In this section we turn our focus from new patent applications to the entire stock of patents in the ICT equipment industry, i.e., patents that have been granted since 1976 absent expired patents. Thus we repeat the analyses of patent flow on the cumulative patent stock. This switch also enables us to include the merger intensity measures in our analyses, as merger intensity is a measure of stock. The switch to the patent stock is interesting mainly because, in new patent applications, entrants may surpass industry incumbents in a relatively short period, but this may not be the case for the cumulative patent stock. Leading industry incumbents, even if they lose their edge in new patents, will enjoy the benefits of their prior patents for a while. Microsoft

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<sup>22</sup> 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).



illustrates this lag well. It appears as one of the top five patent applicants in a technology class for the first time in 1992. However, it appears as one of the top five holders of cumulative patent stock in a technology class only three years later, in 1995.

The measure of concentration in this section is the ownership share of top twenty-five companies in the entire patent stock,  $C25_{stock}$ . As opposed to using two-year periods as the unit of time, in the stock analyses we use each year as a separate period because stock variables do not exhibit the scarcity issue of the flow variables. As was the case with flow, we observe that the share of top twenty-five firms in patent stock decreases from 51 percent in 1986 to 39 percent in 2007 for technology class 385, Optical Waveguides.

The deconcentration trend in patent stock prevails across technology classes in ICT equipment. Table 3 reports the annual averages of  $C25_{stock}$  values across the technology classes in our sample. The average share of top twenty-five firms in the stock follows a trend downward, from 65 percent in 1986 to 51 percent in 2005, and plateaus thereafter. This deconcentration trend also holds for the entire sample of patents, with a reduction from 59 percent in 1986 to 50 percent in 2007 (see Table G.4). As in the patent flow case, we see no clear relationship between the presence of large leading firms and this deconcentration trend. Table 4 reports the number of firms responsible for 90 percent or more of the reduction between 1986 and 2007; in only six technology classes do three or fewer firms account for this change. In the remaining classes the reduction comes from a group of companies, providing evidence that the divestiture of AT&T, or the activities of Motorola or IBM, cannot account singlehandedly for this trend. In unreported results, we observe a similar trend in the entire sample of patents.

### **Role of acquisitions**

We have shown that the top twenty-five firms in the ICT equipment industry hold a smaller share of the patent flow and stock than they did three 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 7. 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 7 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 7 reports patents acquired by all firms.

In Table 7 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. The following section puts the various, competing explanations of deconcentration in patent stock ownership into a single framework.

### **Composition of ownership in patent stock: 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 5 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:

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

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. The use of

patent stock enables us to include M&A intensity, i.e., the measure of transferred patents through M&A activity in a technology class, in our analyses as an additional variable.

We present the fixed effects model of patent stocks in Table 6. 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.<sup>23</sup> We clustered the standard errors by technology class.<sup>24</sup> 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 2 reports the coefficient estimates of the time fixed effects from the model, which indicate a secular deconcentration over the years, as was the case with the flow of patents. 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.

The results (somewhat) mimics our observations on patent flow. 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

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<sup>23</sup> 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.

<sup>24</sup> Two-way clustering of the standard errors by class and time does not change our statistical inferences.

( $=0.25 * 0.32$ ) reduction in concentration, which is roughly the same level of deconcentration induced by time fixed effects, with the difference that the new entry impact is based on only one period's impact.

As in the flow analyses, 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.

As in the flow analyses, the lateral entry 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 slower pace of change in the stock of patents than in the flow 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.

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.<sup>25</sup>

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.

The main results across all models show that growth in the number of firms is an important driver 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 innovative 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

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<sup>25</sup> 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.

firms with established product market presence for external innovation. 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 innovation.

Overall we find a substantial decline in concentration. The data show that the deconcentration arises in every measure of the trend. It is present both in the ownership of new patent applications and 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 does not impact our patent flow variables, as they are based on the patent applications within each year; however, it 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.

## References

- Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and Innovation: An Inverted-U Relationship. *The QJE*, 701-728.
- Ahuja, G., & Katila, R. (2001). Technological acquisitions and the innovation performance of acquiring firms: A longitudinal study. *SMJ*, 22(3), 197-220.

- Arora, A., Fosfuri, A., & Gambardella, A. (2004). *Markets for technology: The economics of innovation and corporate strategy*. MIT press.
- Arora, A., Gambardella, A.. (2010). *The Market for Technology*. In *Handbook of the Economics of Innovation*, vol. 1, ed. Bronwyn H. Hall and Nathan Rosenberg, 641-678. Amsterdam: Elsevier/North Holland.
- Asker, J., Farre-Mensa, J., & Ljungqvist, A. (2011). Comparing the investment behavior of public and private firms (No. w17394). NBER.
- Bresnahan, T. F., & Greenstein, S. (1999). Technological competition and the structure of the computer industry. *The Journal of Industrial Economics*, 47(1), 1-40.
- Cassiman, B., & Valentini, G. (2015). Open innovation: Are inbound and outbound knowledge flows really complementary? *Strategic Management Journal*.
- Chang, S. J., & Wu, B. (2014). Institutional barriers and industry dynamics. *Strategic Management Journal*, 35(8), 1103-1123.
- Chen, P. L., Williams, C., & Agarwal, R. (2012). Growing pains: Pre-entry experience and the challenge of transition to incumbency. *SMJ*, 33(3), 252-276.
- Chesbrough, Hank. 2003. *Open Innovation: The New Imperative for Creating and Profiting From Technology*. Boston: HBS Press.
- Crandall, Robert W., and Leonard Waverman. 1995. *Talk Is Cheap*. The Brookings Institute.
- Gans, J., D. Hsu, and S. Stern. 2002. When Does Start-Up Innovation Spur the Gale of Creative Destruction? *Rand Journal of Economics*. 33(4): 571–586.
- Gawer, Annabelle, 2010. *Platforms, Markets, and Innovation*. Edward Elgar Pub.
- Greenstein, Shane. 2010. “Innovative Conduct in U.S. Commercial Computing and Internet Markets.” In *Handbook on the Economics of Innovation*, ed. Bronwyn Hall and Nathan Rosenberg, 477-538. Burlington, MA: Academic Press.
- Greenstein, Shane. 2015. *How the Internet Became Commercial: Innovation, Privatization, and the Birth of a new Network*. Princeton University Press; Princeton N.J.
- Griliches, Z. 1989. "Patents: Recent Trends and Puzzles," *Brookings Pap. Econ. Act., Microeconomics*, 291-330.
- Griliches, Z. 1990. Patent Statistics as Economic Indicators: A Survey. *Journal of Economic Literature*. 28: 1661–1707.
- Hall, B. 2005. Exploring the Patent Explosion. *Journal of Technology Transfer*. 30:35-48.
- Hall, B, A. Jaffe, and M. Trajtenberg. 2005. Market Value and Patent Citations. *Rand Journal of Economics*. 36: 16–38.
- Hall, B, and Megan MacGarvie. 2010. The Private Value of Software Patents. *Research Policy*. 39 (7): 994–1009.
- Hall, B., A. Jaffe, and M. Trajtenberg. 2001. “The NBER Patent Citations Data File: Lessons, Insights and Methodological Tools.” NBER Working Paper No. 8498.
- Hashai, N. (2015). Within-industry diversification and firm performance—an S-shaped hypothesis. *Strategic Management Journal*, 36(9), 1378-1400.
- Kim, J., and G. Marschke. 2004. Accounting for the Recent Surge in U.S. Patenting: Changes in R&D Expenditures, Patent Yields, and the High Tech Sector. *Economics of Innovation and New Technology*. 13(6): 543-558.
- Kortum, S., and J. Lerner. 1999. What Is Behind the Recent Surge in Patenting? *Research Policy*. 28:1-22.

- Lee, G. K. (2007). The significance of network resources in the race to enter emerging product markets: The convergence of telephony communications and computer networking, 1989–2001. *Strategic Management Journal*, 28(1), 17-37.
- Leiponen, A., & Helfat, C. E. (2010). Innovation objectives, knowledge sources, and the benefits of breadth. *Strategic Management Journal*, 31(2), 224-236.
- Mauri, A. J., & Michaels, M. P. (1998). Firm and industry effects within strategic management: An empirical examination. *SMJ*, 19(3), 211-219.
- Miller, D. J. (2006). Technological diversity, related diversification, and firm performance. *Strategic Management Journal*, 27(7), 601-619.
- Misangyi, V. F., Elms, H., Greckhamer, T., & Lepine, J. A. (2006). A new perspective on a fundamental debate: A multilevel approach to industry, corporate, and business unit effects. *Strategic Management Journal*, 27(6), 571-590.
- Nagaoka, S., K. Motohashi, and A. Goto. 2010. "Patent Statistics as an Innovation Indicator." In *Handbook of the Economics of Innovation*, ed. B. H. Hall and N. Rosenberg. Amsterdam: Elsevier.
- Netter, J., M. Stegemoller, and M. B. Wintoki. 2011. Implications of Data Screens on Merger and Acquisition Analysis. *Review of Financial Studies*. 24: 2316–2357.
- Ozcan, Yasin, and Shane Greenstein, 2013. "Composition of R&D Activity in ICT Equipment R&D." *Loyola University Chicago Law Journal*. 45:7:2. Winter.
- Rosenbloom, R. S., and W. J. Spencer, eds. 1996. *Engines of Innovation: U.S. Industrial Research at the End of an Era*. Boston: Harvard Business School Press.
- Schankerman, M., and A. Pakes. 1986. Estimates of the Value of Patent Rights in European Countries during the Post-1950 Period. *The Economic Jour*. 96: 1052-1076.
- Schmookler, Jacob. 1951. *Invention and Economic Development*. Unpublished Ph.D. Dissertation, University of Pennsylvania.
- Serrano, C. J. 2010. The Dynamics of the Transfer and Renewal of Patents. *RAND Journal of Economics*. 41: 686-708.
- Skilton, P. F., & Bernardes, E. (2015). Competition network structure and product market entry. *Strategic Management Journal*, 36(11), 1688-1696.

**Table 1: Distribution of  $C25_{flow}$  values**

| <b>Year Group</b> | <b>Mean (%)</b> | <b>St. Dev. (%)</b> | <b>10%</b> | <b>25%</b> | <b>50%</b> | <b>75%</b> | <b>90%</b> |
|-------------------|-----------------|---------------------|------------|------------|------------|------------|------------|
| 76-77             | 86              | 15                  | 66         | 77         | 88         | 100        | 100        |
| 78-79             | 83              | 16                  | 65         | 72         | 80         | 100        | 100        |
| 80-81             | 81              | 16                  | 63         | 71         | 80         | 100        | 100        |
| 82-83             | 80              | 17                  | 59         | 68         | 75         | 100        | 100        |
| 84-85             | 77              | 19                  | 51         | 67         | 72         | 100        | 100        |
| 86-87             | 73              | 18                  | 49         | 63         | 71         | 84         | 100        |
| 88-89             | 71              | 16                  | 51         | 60         | 68         | 81         | 100        |
| 90-91             | 70              | 15                  | 52         | 61         | 68         | 77         | 91         |
| 92-93             | 67              | 13                  | 49         | 60         | 66         | 74         | 82         |
| 94-95             | 62              | 11                  | 43         | 60         | 65         | 70         | 73         |
| 96-97             | 60              | 12                  | 43         | 53         | 60         | 69         | 74         |
| 98-99             | 58              | 11                  | 38         | 53         | 61         | 66         | 71         |
| 00-01             | 56              | 12                  | 35         | 50         | 57         | 62         | 72         |
| 02-03             | 55              | 13                  | 36         | 48         | 56         | 60         | 72         |
| 04-05             | 59              | 13                  | 41         | 53         | 59         | 66         | 77         |
| 06-07             | 62              | 14                  | 46         | 53         | 60         | 73         | 82         |

Notes: Evolution of the patent application *flow* share for top twenty-five firms that are ultimately granted on or before 2010. Each row corresponds to a two-year time period. The sample includes patent applications from thirty patent technology classes in the ICT equipment industry, and the highest quartile of patents, where quality is measured by citations received.

**Table 2: No. of companies accounting for 90% of change in  $C25_{flow}$** 

| No. of Companies | No. of Classes |
|------------------|----------------|
| 1-3              | 3              |
| 4-19             | 13             |
| 20-25            | 11             |
| <b>Total</b>     | <b>27</b>      |

Notes: The number of ICT equipment industry patent technology classes that went through a deconcentration of patent flow ownership from 1976 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: Distribution of  $C25_{stock}$  values**

| <b>Year Group</b> | <b>Mean (%)</b> | <b>St. Dev. (%)</b> | <b>10%</b> | <b>25%</b> | <b>50%</b> | <b>75%</b> | <b>90%</b> |
|-------------------|-----------------|---------------------|------------|------------|------------|------------|------------|
| 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 4: 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              |
| <b>Total</b>     | <b>29</b>      |

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

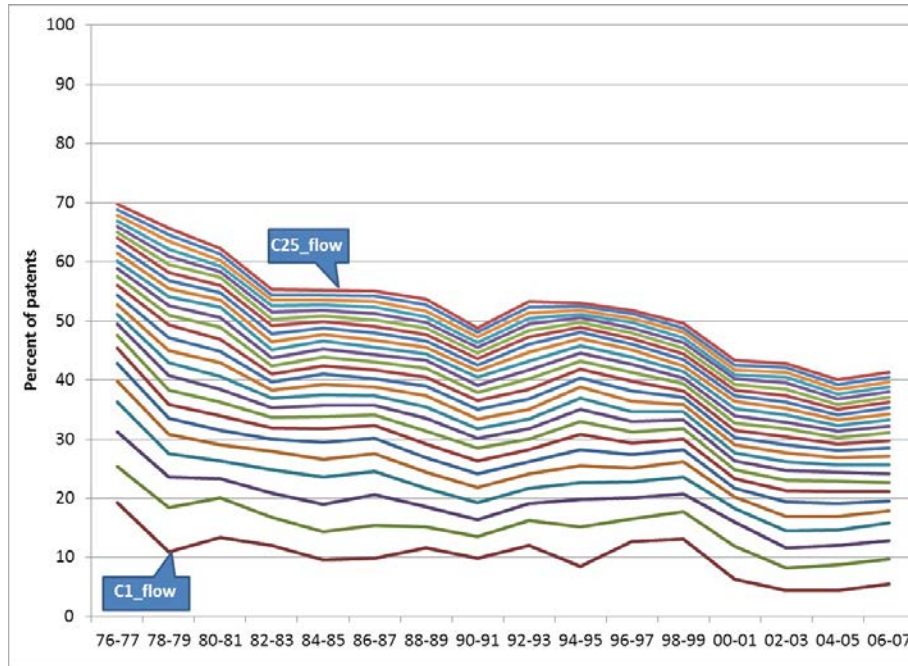
Notes: Regressions are ordinary least squares, with S.E. in parentheses. \*\*\*, \*\*, \* indicate significance at the 1%, 5%, and 10% levels respectively. Standard errors are clustered by class. An observation is a patent technology class and a calendar year. N is 660. Each model includes technology 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 7: Cumulative ICT equipment patent stock**

| Year | Patent Stock |          |        | Share Transferred         |                            |
|------|--------------|----------|--------|---------------------------|----------------------------|
|      | All ICT      | Acquirer | Target | Target/<br>All ICT<br>(%) | Target/<br>Acquirer<br>(%) |
| 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                         |

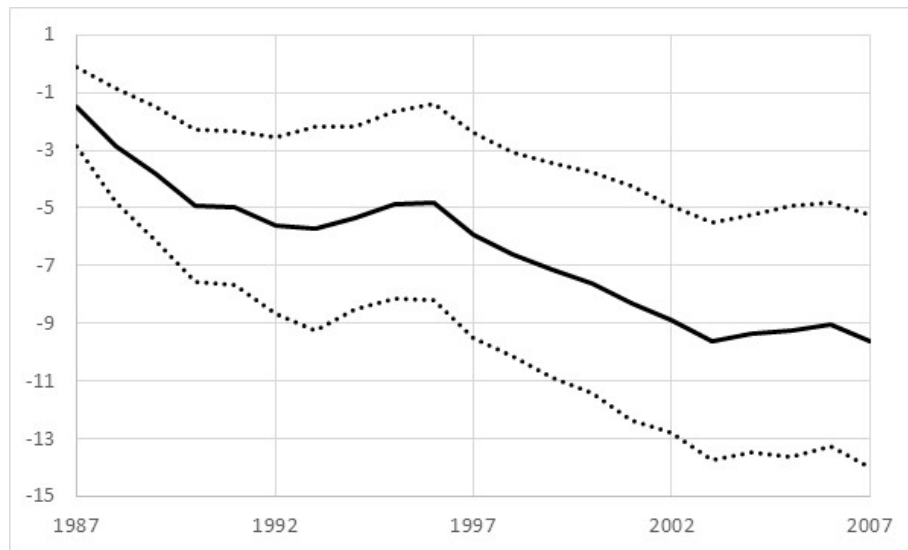
Notes: Cumulative ICT equipment industry patent *stock* transfers through mergers against the entire ICT equipment industry patent *stock* from 1979 to 2007, at the highest quartile patent quality level, where quality is measured by citations received. The patent *stock* is the discounted sum of unexpired 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.





**Figure 1: Patent flow 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 years are grouped into two year cells. The concentration is measured by the share of top  $i$  firms in terms of patent applications within each two-year cell, where  $i$  ranges from one to twenty-five.



**Figure 2: Patent stock – time fixed effects coefficient estimates**

Notes: Coefficient estimates of time fixed effects from Model 1 in Table 6. 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.