

Di Addario, Sabrina; Feng, Zhexin; Serafinelli, Michel

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## DISCUSSION PAPER SERIES

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# Inventors' Coworker Networks and Innovation

**Sabrina Di Addario**

*Bank of Italy*

**Zhexin Feng**

*University of Essex*

**Michel Serafinelli**

*King's College London, CESifo, IZA and CReAM*

OCTOBER 2024

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**IZA – Institute of Labor Economics**

Schaumburg-Lippe-Straße 5–9  
53113 Bonn, Germany

Phone: +49-228-3894-0  
Email: [publications@iza.org](mailto:publications@iza.org)

[www.iza.org](http://www.iza.org)

## ABSTRACT

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# Inventors' Coworker Networks and Innovation\*

This paper presents direct evidence on how firms' innovation is affected by access to knowledgeable labor through co-worker network connections. We use a unique dataset that matches patent data to administrative employer–employee records from “Third Italy”—a region with many successful industrial clusters. Establishment closures displacing inventors generate supply shocks of knowledgeable labor to firms that employ the inventors' previous co-workers. We estimate event-study models where the treatment is the displacement of a “connected” inventor (i.e., a previous coworker of a current employee of the focal firm). We show that the displacement of a connected inventor significantly increases connected inventors' hiring. Moreover, the improved access to knowledgeable workers raises firms innovative activity. We provide evidence supporting the main hypothesized channel of knowledge transfer through firm-to-firm labor mobility by estimating IV specifications where we use the displacement of a connected inventor as an instrument to hire a connected inventor. Overall, estimates indicate that firms exploit displacements to recruit connected inventors and the improved capacity to employ knowledgeable labor within the network increases innovation.

**JEL Classification:** J60, O30, J23

**Keywords:** social connections, firm-to-firm labor mobility, patents, establishment closure

**Corresponding author:**

Michel Serafinelli  
Department of Economics  
University of Essex  
Wivenhoe Park  
Colchester CO4 3SQ  
United Kingdom

E-mail: [michel.serafinelli@essex.ac.uk](mailto:michel.serafinelli@essex.ac.uk)

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# 1 Introduction

A prominent feature of the labor market is firms' tendency to recruit through informal networks: surveys across OECD countries indicate that 15–50 percent of jobs are found through social connections, while around 70 percent of US companies encourage referral-based hiring (Pellizzari, 2010; Saygin, Weber, & Weynandt, 2019; Friebe, Heinz, Hoffman, & Zubanov, 2019). Researchers have speculated that firms benefit from using informal networks, for example, because of a reduction in information asymmetries, turnover, and hiring costs. Studies exploring the possible advantages in terms of innovation are limited, which is a pitfall given the importance of innovation for economic growth. Inventors are strategic to innovation but are a scarce factor of production: each given firm has access to a very limited supply of inventors for recruitment with reduced frictions, and thus informal connections could be a privileged channel to recruit them (Dustmann, Glitz, Schönberg, & Brücker, 2016).

This is the first paper that presents direct evidence of the impact of increased access to knowledgeable labor (i.e., inventors) through co-worker network connections on firms' innovation.<sup>1</sup> In confronting the non-trivial measurement challenges involved, we take advantage of a unique dataset that matches the universe of European Patent Office (EPO) patents to administrative employer–employee records for the period 1987–2008 from the so-called "Third Italy"—a macro-area in the North-East of the country characterized by a high concentration of successful industrial clusters. We build on these data by constructing the firm's co-worker network of inventors; to our knowledge, this is the first study to have done so. Firms' innovative activity is proxied by the number of patent applications to the EPO.

Our empirical strategy exploits the establishment closures that displace inventors in the labor market, generating a shock to the supply of knowledgeable labor. Our approach is similar to that of Eliason, Hensvik, Kramarz, & Skans (2017): we argue that the inventor displacement shock may be more specific to connected firms, who may then experience increased access to knowledgeable labor and thus an improvement in their chances of patenting compared to non-connected firms.

We estimate event-study models where the treatment is the displacement of a connected inventor. This research design allows us to test for the presence of pre-trends in the outcomes and enables us to recover the dynamics of the effects of interest. We document that the displacement of a connected inventor significantly increases the hiring of connected inventors.<sup>2</sup> Moreover, we show that improved access to knowledgeable work-

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<sup>1</sup>In this paper, firm  $j$  is "connected" to an inventor if the latter has previously been a coworker of at least one of firm  $j$ 's employees.

<sup>2</sup>The hires of non-connected inventors are not affected.

ers raises firms innovative activity. Specifically, in the event study, the estimated average increase in patent applications in the five years after a connected inventor's displacement is 0.27 standard deviations. The baseline analysis uses simple patent counts but conclusions are very similar when we use citation-weighted patent counts.

We then verify empirically the evidence in favor of our main hypothesized channel: knowledge transfer through firm-to-firm labor mobility. The underlying intuition is that knowledge, which is mostly embedded in knowledge workers, spreads when these workers move across firms (Dasgupta, 2012). Specifically, we assess the effect of hiring a connected inventor on firms' innovative activity by an instrumental variable approach, using the displacement of a connected inventor as an instrument for the hire of a connected inventor. Since inventors are scarce, firms compete to hire them; the firms connected to displaced inventors through their employees may have a preferential channel to recruit them. The impact of a connected inventor displacement on the firm's capability to innovate then occurs through hiring. An alternative hypothesis is that hiring decisions are taken based on nepotism (Beaman & Magruder (2012); Wang (2013)). A positive estimated effect in the IV regression is consistent with the hypothesis that informal connections reduce hiring frictions and channel valuable information to firms, while a negative impact is consistent with the hypothesis that nepotism plays a significant role in the recruitment process.

The IV estimates indicate that hiring a connected inventor raises innovation by approximately 0.6 patent applications—which is equivalent to an increase of 1.71 standard deviations.<sup>3</sup> This additional output is not restricted to the patents authored or co-authored by the newly hired connected inventor, but it also refers to the patents exclusively authored by the other workers of the destination firm. Thus, the addition of a new inventor appears to "fertilize" the firm, spurring the development of new patent applications by its employees.

A potential identification concern arises in case shocks to the supply of knowledgeable labor partly capture market-level shocks (Cestone, Fumagalli, Kramarz, & Pica, 2016; Gathmann, Helm, & Schönberg, 2020)). We do not expect this to be a major issue in our context, since the closing establishments in our sample are mostly small to medium-sized (median of around 100 employees), and thus the market effects originating from their closure are likely to be rather limited. Nevertheless, to allay concerns of market effects, we also control for the number of displaced workers in the local labor market (LLM) and industry. Furthermore, we perform a "placebo"-type analysis, showing no effect from the displacement of inventors with connections to other firms in the same LLM and industry (i.e., firms different from the focal firm). Specifically, we investigate how innovation

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<sup>3</sup>When interpreting these estimates it is important to highlight that the hire of a connected inventor is a major change in terms of the workforce for the average firm in our data (Section 3.2).

at firm  $j$  reacts to the displacement of inventors who are connected to other firms in the same LLM and industry but not to the focal firm  $j$ .<sup>4</sup> The results indicate that the estimated average change over the five years following the placebo event is non-significant. While we cannot completely rule out the possibility of market effects, the placebo result does not appear consistent with this possibility.

Overall, our evidence indicates that firms take advantage of displacements to recruit connected inventors. Moreover, the improved ability to employ connected inventors increases firms patenting activity. More generally, our estimates suggest that informal connections involving knowledgeable workers reduce hiring frictions and channel valuable information to firms. We show that this process benefits firms' innovation by expanding the availability of knowledgeable labor. The percentage of connected inventor hires is markedly larger than the connected employee share reported in other studies that do not focus on inventors. This suggests that network effects are stronger for inventors than for the average worker. The documented increase in firms patenting activity agrees with our hypothesis of knowledge transferred through inventor mobility, while it is not consistent with the alternative hypothesis that nepotism plays an important role in hiring decisions.

The remainder of this paper is organized as follows. Section 2 discusses the relation of our paper to previous research. Section 3 presents the data and provides some background information for "Third Italy", while Section 4 discusses our econometric strategy and presents the results and various robustness checks. Finally, Section 5 concludes the paper.

## 2 Relation to Previous Research

Our work is mainly related to the literature on networks, workers' mobility, and innovation.

First, our paper is linked to research on the impact of networks on the labor market. A first set of studies within this theme uses matched employer–employee data to explore network effects on the labor market and related outcomes. The work of [Eliason et al. \(2017\)](#) is closest to our paper. In particular, the authors assess the causal effect of co-worker connections in the context of displacement and analyze firm-level outcomes, focusing on the impact on total hires, value-added, and job separations. Our empirical strategy builds directly on theirs, using a similar type of supply shock and conceptual framework. Using an armed-force test, [Hensvik & Skans \(2016\)](#) report that firms are able to hire workers with higher cognitive skills when recruiting a previous colleague of their current employees. [Kramarz & Skans \(2014\)](#) show that family ties are important to determine where young workers find their first job, while [Eliason, Hensvik, Kramarz, & Skans \(2023\)](#) focus on

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<sup>4</sup>See [Eliason et al. \(2017\)](#), p.5.

whether social connections can increase inequality and determine that high-wage workers sort in high-wage firms because of their networks ("birds of a feather flock together"). Finally, [Akcigit, Baslandze, & Lotti \(2023\)](#) and [Diegmann, Pohlen, & Weber \(2024\)](#) study the role of firms' political connections in Italy and Germany, respectively.

A second body of work within the network literature analyzes the transmission of information through connections. [Cingano & Rosolia \(2012\)](#) and [Glitz \(2017\)](#) find that having thicker networks of employed former coworkers increases the re-employment probability of workers displaced after a firm closure. [Pellizzari \(2010\)](#) hypothesizes that finding a job through the network improves the quality of the match and thus raises wages, but finds heterogeneous empirical results across countries. [Schmutte \(2015\)](#) reports evidence of the positive sorting of high-ability workers to high-paying firms when their neighbors are employed in high-paying firms. [Battisti, Peri, & Romiti \(2016\)](#) determines that people who emigrate to German districts with larger co-ethnic networks are more likely to find a job soon after arrival (see [Topa \(2011\)](#) for a review of additional studies in this area). [Saygin et al. \(2019\)](#) combines features of these first two sets of studies and analyzes work-related networks from the standpoint of both job seekers and hiring firms, using matched employer–employee data. Their evidence indicates an important contribution of networks in the transmission of job information and strongly suggests that the main channels are knowledge transfer on demand-side conditions and job referrals.

A final set of studies related to networks analyses referral programs on a variety of labor market outcomes. For example, [Dustmann et al. \(2016\)](#) and [Glitz & Vejlin \(2021\)](#) document a larger initial wage premium and longer job tenure for referred workers. [Burks, Cowgill, Hoffman, & Housman \(2015\)](#) find that in call centers and trucking, referred employees yield higher profits per worker than non-referred employees due to lower turnover and recruiting costs, while in high-tech sectors they produce more patents. [Friebel et al. \(2019\)](#) finds that having an employee referral program reduces attrition and decreases firm labor costs.

We contribute to the literature on networks by specifically analyzing inventors and innovation, and by using a research design that permits the testing of the presence of pre-trends in the outcomes; it also enables us to recover the dynamics of the effects of interest. Although the mechanisms we document may also apply to other types of workers and outcomes, we focus on inventors and patenting firms since they are key drivers of economic growth and are deemed to foster sizable positive social externalities ([Bloom, Schankerman, & Van Reenen, 2013](#); [Bell, Chetty, Jaravel, Petkova, & Van Reenen, 2019](#)).

Moreover, while the issues analyzed in this paper are of general interest, the specific case of "Third Italy" is also important. This is a macro-region rich in networks of specialized producers frequently organized in industrial districts (IDs). IDs have been effective

in promoting and adapting to technological change during the period of analysis (1987–2008). This large economic area has been the focus of much research, both in Europe and in the United States.<sup>5</sup>

Second, our paper is related to the literature on R&D spillovers, the mobility of R&D personnel, and the implications of firm-to-firm labor mobility for firm-level outcomes. [Fons-Rosen \(2013\)](#) finds that foreign direct investment has a greater impact on the host economy in terms of knowledge diffusion when firms relocate inventors from the already established R&D labs in their home country to newly developed labs in the host country. [Maliranta, Mohnen, & Rouvinen \(2009\)](#) report that the firms involved in non-R&D activities hiring workers from R&D-intensive firms tend to perform better.<sup>6</sup> [Balsvik \(2011\)](#) offers a detailed account of the productivity gains linked to worker flows from foreign multinationals to domestic firms in Norway.<sup>7</sup> [Parrotta & Pozzoli \(2012\)](#) provide evidence from Denmark regarding the positive impact of the recruitment of "knowledge carriers" –technicians and highly educated workers recruited from a donor firm—on a firm's value-added. [Stoyanov & Zubanov \(2012\)](#) show that Danish firms that hire workers from more productive firms increase their productivity. [Fons-Rosen, Kalemli-Ozcan, Sorensen, Villegas-Sanchez, & Volosovych \(2017\)](#) explore the impact of FDI on the productivity of host-country firms and show that inventor mobility across sectors is a key channel of technology transfer. [Serafinelli \(2019\)](#) finds evidence of labor market-based knowledge spillovers in the Veneto region of Italy.

Our findings are consistent with these empirical contributions. Unlike the above authors, who focus on the relationship between labor mobility and productivity, we also shed light on a broader question: how firms' innovation is affected by access to knowledgeable labor through co-worker network connections, particularly through inventors. Although inventors are not the only workers who may transfer relevant information from one firm to another, they undoubtedly have the largest potential to do so.

Third, our paper is related to the literature on knowledge diffusion, inventors, and innovation ([Kantor & Whalley, 2014](#); [Fons-Rosen, Scrutinio, & Szemerédi, 2016](#); [Moretti,](#)

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<sup>5</sup>[Brusco \(1983\)](#); [Piore & Sabel \(1984\)](#); [Trigilia \(1990\)](#); [Whitford \(2001\)](#); [Becattini, Bellandi, & De Propris \(2014\)](#); [Trigilia \(2020\)](#)

<sup>6</sup>[Bloom et al. \(2013\)](#) determine the impact of technology spillovers and that of the product market rivalry of R&D (negative business-stealing effects on the product market). They analyze a 20-year panel of US firms and show that knowledge spillovers quantitatively dominate product market spillovers. Related contributions on knowledge spillovers include [Breschi & Lissoni \(2001\)](#), [Dechezleprêtre, Martin, & Mohnen \(2017\)](#), and [Crescenzi & Gagliardi \(2018\)](#). [Kaiser, Kongsted, & Rønde \(2015\)](#) show that the mobility of R&D personnel enhanced the patenting output of Danish firms during the period 1999–2004. Other papers combine register data with patent data and study features of the work history of inventors (see, for example, [Kline, Petkova, Williams, & Zidar \(2019\)](#), [Depalo & Di Addario \(2014\)](#), and [Di Addario & Wu \(2024\)](#)).

<sup>7</sup>Likewise, [Poole \(2013\)](#) finds a positive effect of the share of new workers previously employed by foreign-owned firms on wages paid in domestic firms in Brazil.

2021; Ganguli, Lin, & Reynolds, 2020; Huang, Moretti, & Xia, 2023).<sup>8</sup> In particular, our study is related to research investigating network effects in science. For example, Mohnen (2022) shows that network position is crucial in determining scientific production by facilitating access to other scientists non-redundant knowledge through coauthorship links.<sup>9</sup> Another related body of the literature analyzes peer effects in the workplace induced by knowledge spillovers and finds mixed evidence. On the one hand, Waldinger (2010), for example, finds that faculty quality is a very important determinant of PhD student outcomes. On the other hand, Cornelissen, Dustmann, & Schönberg (2017) obtain only small peer effects on wages in high-skilled occupations, and Waldinger (2012) shows that even very high-quality scientists do not affect the productivity of their local peers. Other papers within this body of literature, particularly on social pressure, report productivity spillovers (Mas & Moretti, 2009; Bandiera, Barankay, & Rasul, 2010). A final set of related studies focuses on the mobility of immigrant scientists. For example, Moser, Voena, & Waldinger (2014) analyze chemical inventions and compare the changes in US patenting by US inventors in the research fields of German Jewish émigrés to changes in US patenting by US inventors in the fields of other German chemists. They show that US patenting activity has increased in the research fields of German-Jewish refugees who emigrated after 1933.

### 3 Data and Descriptive Statistics

#### 3.1 Data

##### Administrative Records and Patent Data

We build on the database provided by Depalo & Di Addario (2014), who linked patent data from the EPO Worldwide Patent Statistical Database (PATSTAT, henceforth) and the employer–employee-matched data from the Italian Social Security Institute (Istituto Nazionale di Previdenza Sociale, INPS) to study inventors returns to patents. Specifically, we add to their work by computing the network for each firm in the sample.

The INPS dataset has information on all private sector employees in the period 1987–2008. In particular, it contains register-based information for any job lasting at least one day, thus allowing for the reconstruction of the employment history of each worker in the analyzed period. The available information at the individual level includes: age; gender; municipality of residence and municipality of birth; work status (blue collar, white collar,

<sup>8</sup>A related body of work focuses on the effect of innovation on productivity and employment growth (Hall, Lotti, & Mairesse, 2008; Marin & Lotti, 2016).

<sup>9</sup>More generally, several studies explore co-author relationships and social ties in research (Jaravel, Petkova, & Bell, 2018; Colussi, 2018; Azoulay, Fons-Rosen, & Graff Zivin, 2019; Zacchia, 2020).

manager, and other); type of contract (full-time versus part-time); and gross yearly earnings. The information on firms includes average gross yearly earnings, yearly number of employees, industry, location (at the municipality level), and date of firm opening and closure.

PATSTAT contains the universe of patent applications and grants presented at the EPO by any Italian "applicant" (i.e., the firm submitting a patent application and retaining the relative property rights). The database provides a detailed description of each patent submission, including its title, abstract, and technological field, the name and address of all its inventors and applicants, the dates of application filing, publication, and grant obtainment, and the citations received.

PATSTAT does not have a reliable firm identifier. Thus, INPS matched the two datasets with an exact procedure ensuring that, in the year of submission, the inventors appearing in each patent were indeed employed by an INPS firm corresponding to the PATSTAT applicant.<sup>10</sup> The resulting dataset includes the full work history of the inventors<sup>11</sup>, namely, social security information for all firms in which inventors have worked during their career, also covering firm-year observations before their first patent application. More generally, our dataset includes the full work history of the employees working in any of the patenting firms, even if they moved from/to a non-patenting firm. Thus, the dataset includes both firms that exhibit one or more patent applications during the sample period and firms that have none.

In this paper, we assign the status of "inventor" to an employee only after her/his first patent application. More precisely, we define a worker as being an inventor in year  $m$  if she/he has already submitted a patent application in year  $t \leq m$ . Note that we also observe all the co-workers of these inventors for all the establishment-year observations.

### Co-worker Network

We construct the firm's network using co-worker links, detected from the employment history of each worker. More precisely, the employee's network comprises all her/his former co-workers in the previous five years, while the firm's network is the collection of the co-worker networks of each incumbent employee.

The co-worker network is constructed for each establishment and year. In the sample, we include only establishments with less than 500 employees to reduce the incidence of

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<sup>10</sup>See [Depalo & Di Addario \(2014\)](#) for an in-depth description of the matching procedure. In summary, the datasets were merged in several steps. First, the authors attributed VAT codes to PATSTAT applicants based on their name and location, after verifying them with four alternative datasets (Cebi, Infocamere, INPS, and Orbis). Then INPS linked PATSTAT applicants to all possible INPS establishments that had the same VAT identifier and the same name and location (at the municipality level). Finally, INPS verified in its records that there was a correspondence between INPS employees/firms and PATSTAT inventors/applicants.

<sup>11</sup>We have a total of 5,888 inventors in our data

imprecise connections, since the chances of having real contact among the workers are low in very large establishments.

### **Establishment Closures and Displaced Inventors**

Our empirical strategy uses establishment closures to identify the supply shock of knowledgeable workers within a firm's network. Considering the five-year interval necessary to form the firm's network, we are interested in the closures between 1992 and 2008.

To identify "true" establishment closures, namely, those that are not a result of a merger, a change of tax identifier, or a spin-off, we analyze worker flows from closing establishments and denote a closure as "true" whenever the maximum cluster of outflow from the closing establishment to any other firm is below 50 percent of the workforce of the closing establishment—estimates are qualitatively similar if we use a 30 percent threshold.

Using the information on establishment closures, we can detect all the employees (independently of whether they are inventors) who are subject to displacement. We denote workers as displaced at time  $t$  if they terminate their job in the same year that their establishment closes. In this paper, we are interested in the displacement of inventors, who account for approximately 0.004 percent of all the workers displaced because of an establishment closure.

### **Macro-region of Study: "Third Italy"**

This paper covers the large economic area of "Third Italy", which includes the following administrative regions located in the Center-North-East of the country: Emilia-Romagna; Friuli-Venezia Giulia; Marche; Toscana; Trentino-Alto Adige/Südtirol; and Veneto. The combined population of these regions contains around 16.9 million people (28 percent of the total population in Italy). In the 16-year analysis period, the labor market of this macro-area was overall characterized by a good performance in terms of total employment, job creation in manufacturing, migration flows, and business creation (see, for example, [De Blasio & Di Addario \(2005\)](#)), especially in Emilia-Romagna and Veneto.

Our territorial units are the LLMs, which are territorial groupings of municipalities that partition the entire Italian territory and have been singled out by the National Institute of Statistics based on working-day resident population commuting flows.<sup>12</sup> LLMs can be considered self-contained labor markets since their residing population largely overlaps with the working population. In 1991, the almost 1,900 municipalities (*Comuni*) in our six administrative regions were grouped into about 235 LLMs. A sizable fraction of these

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<sup>12</sup>Also France, with its *zones d'emploi*, and the UK, with its travel-to-work areas, partition their territories into areas with similar characteristics.

LLMs are thick with small- and medium-sized manufacturing firms within the so-called industrial districts (IDs). These firms are spatially concentrated and generally locally owned. The system is characterized by a very detailed inter-firm division of labor among a large number of firms specialized into one or a few stages of a main manufacturing production (main industry). Firms can be vertically, horizontally, and diagonally linked, and can be specialized in a few phases of the productive process, in making contacts with the final markets, in service activities, or in manufacturing activities complementary to the main industry. The vicinity of firms creates labor market pools of specialized workers with industry-specific skills.<sup>13</sup> IDs are thus thick of networks.

A distinctive feature of "Third Italy" is the large presence—since the early 1970s—of networks of flexible producers frequently organized in IDs, with the level of industrial value added often greatly exceeding the national average, particularly in the areas around Bologna, Padua, and Verona (see, for example, [Tattara & Valentini \(2010\)](#) and [Trigilia \(2020\)](#)). Germany's Baden-Wuerttemberg and the British Motor Valley (centered in Oxfordshire and stretching into East Anglia and Surrey) are other examples of similar regional network-based industrial systems. Additional examples have been identified in recent decades in Japan, Scandinavia, Spain, and the United States ([Saxenian, 1994](#); [Henry & Pinch, 2000](#); [Becattini et al., 2014](#)).

Manufacturing firms in the dynamic districts of Third Italy specialize in industries such as metal, mechanical, electrical, and biomedical engineering, automotive, construction materials and technologies, goldsmithing, ceramics, glass, agri-food, furniture, printing and publishing, musical instruments, toys, and fashion-wear. Several of these clusters feature some leader firms, especially in Veneto.<sup>14</sup> While the object of this paper is not specifically the study of IDs, the fact that they are diffused in Third Italy and largely organized in networks—exhibiting high labor mobility—makes them particularly suited for the study of network effects.

### 3.2 Descriptive Statistics

Our main estimation sample consists of all the firms in which at least one inventor has transited between 1992 and 2008, also covering firm-year observations before their first patent application. Given our sample composition (described above), there is a high number of firms (90 percent of the 7,666 firms of our sample) that never patented in our

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<sup>13</sup>"Employers are apt to resort to any place where they are likely to find a good choice of workers with the specialized skills that they require, while men seeking employment naturally go to places where many employers need skills such as theirs and where therefore it is likely they will find a good market" ([Marshall, 1890](#)).

<sup>14</sup>An example is the eyewear district in the province of Belluno, where Luxottica, the world's largest manufacturer of eyeglasses, has production establishments.

observational period. Our panel includes 84,173 firm-year observations, and its main characteristics are summarized in Table 1.

Our main outcome of interest is firms' innovative activity: we take a patent application as a signal of the presence of some innovative output. The first row of Table 1 shows that the mean number of patent applications is 0.038 (the mean number of patent applications restricting to firms that submitted at least one patent application during our sample period is 0.318).

Connected inventor hires amount to 67 percent of the total inventor hires. This is markedly larger than the share of connected worker hires reported in other studies not focusing on inventors, in which, generally, such a share is about 10–15 percent of total hires. This suggests that networks are bound to be a more important hiring channel for inventors than they are for the average worker. The mean number of connected inventor hires in our sample is 0.008 (Table 1, second row). This share is low because our dataset also includes non-innovative firms, but it is nevertheless double that of non-connected inventor hires (equal to 0.004, as shown in the third row of the table).

The fourth and fifth rows of Table 1 report that the average firm employs 47 workers, with a mean co-worker network of 866 individuals. Finally, the last two rows indicate that the mean number of connected and connected non-inventors who are displaced are 0.011 and 2.93, respectively.

Table 2 displays the summary statistics for the number of events, displacements, and inventor hires by year. Connected and non-connected hires are indicated separately. In the period 1992–2008, almost 450 inventors have been displaced. Since each investor could have been connected to more than one company, the number of firms that may have potentially benefited from the displacement of a connected inventor is higher. Overall, 633 firms have been "exposed to the event" of interest. In the same period, more than 680 connected inventors and about 340 non-connected inventors have been hired (independently of whether they had been displaced). The table shows that there is sizable variation over time in the number of events, displacements, and inventor hires.

## 4 Econometric Framework and Results

The objective of our analysis is twofold. First, we aim to estimate the effect of changes in the supply of connected knowledgeable workers on the patent activity of the firm. In particular, we estimate event-study models where the event is the displacement of an inventor connected to firm  $j$ 's current workers. This research design allows us to test for the presence of firm-specific pre-trends in the outcomes and to recover the dynamics of the effect of interest. Second, we aim to provide evidence supporting the main hypothe-

sized channel of knowledge transfer through firm-to-firm labor mobility by estimating IV specifications, where we use the displacement of a connected inventor as an instrument for the hire of a connected inventor

For identification, our econometric analysis exploits establishment closures. The underlying concept is that firm  $j$ 's ability to hire through the network is affected by the displacement (from some other establishment  $q$ ) of inventors connected to  $j$ 's current workers. Specifically, co-worker connections generate a firm-specific shock to the supply of knowledgeable labor by directing the displaced inventors towards the connected firms. As a result, these firms experience an improvement in the chances to recruit connected inventors.

#### 4.1 Event-Study Approach

We use an "event-study" research design (Autor (2003) and Kline (2012)) to investigate how displacement events affect both the hiring of a connected inventor and the patenting activity of the destination firm. Specifically, the regression equation is:

$$Y_{jslt} = \beta_0 + \sum_{\tau} \beta_{\tau} D_{jt}^{\tau} + \beta_n N_{jt} + \beta_d Displaced_{slt} + Trend_{st} + Trend_{lt} + \lambda_j + \alpha_t + u_{jslt}, \quad (1)$$

where the dependent variable is: (a) the number of connected inventors hired by firm  $j$  of industry  $s$  and LLM  $l$  at time  $t$  (from any industry or LLM); or (b) the number of firm  $j$ 's patent applications. We include year dummies ( $\alpha_t$ ) and allow for permanent differences across firms ( $\lambda_j$ ) and industry-specific and LLM-specific trends ( $Trend_{st}$  and  $Trend_{lt}$ ). We also control for network size ( $N_{jt}$ ) and cluster standard errors at the LLM level.

The  $D_{jt}^{\tau}$  are a sequence of "event-time" dummies equal to one when the displacement of a connected inventor is  $\tau$  years away. Thus, the  $\beta_{\tau}$  coefficients characterize the time path of the outcome relative to the date of the event. The event time indicator "-4" is set to 1 for the fourth year preceding the event and for all the years before, and 0 otherwise. The event time indicator "+5" is set to 1 for all the periods successively following the fifth year after the event, and 0 otherwise. Since the sample of treated firms is unbalanced in event time, these endpoint coefficients give different weights to firms experiencing the treatment early or late in the sample period. Therefore, in discussing the treatment effects we concentrate on the event-time coefficients falling in the five-year interval within  $\tau = 0$  and  $\tau = 4$ , which are identified from a nearly balanced panel of firms. We normalize  $\beta_{-1}$  to zero such that all post-treatment coefficients can be considered as treatment effects. We use both the interaction weighted estimator (Sun & Abraham, 2021) and the conventional two-way-fixed effects (TWFE) estimator. Connected inventor displacements occurring later may be different from those occurring earlier, generating cohort-specific treatment

effects. We therefore implement in the main analysis the interaction weighted estimator for an event study. Sun & Abraham (2021) prove that this estimator is consistent for the average dynamic effect at a given relative time even under heterogeneous treatment effects.<sup>15</sup> We use the last cohort as the control cohort (and the never treated as the control cohort in a robustness check). We use the conventional two-way-fixed effects event study design estimation in the sensitivity analysis. An identification concern potentially arises if the shocks directed to the supply of knowledgeable labor also pick up market-level shocks. We do not expect this to be a major issue in our context, since our sample comprises mostly the closures of small to medium-size firms, for which the market effects are likely to be quite limited (the median closing establishment has around 100 employees). Nevertheless, to allay concerns of market effects, we also control for the number of displaced workers in the LLM and industry ( $Displaced_{slt}$ ). Estimates are almost identical if we split this variable into displaced inventors and displaced non-inventors. In Section 4.3, we also perform a "placebo"-type analysis, exploiting the displacement of inventors connected to other firms in the same LLM and industry.

#### 4.1.1 Evidence: Recruitment of Connected Inventors

We now turn to investigating how the hiring of connected inventors is affected by displacement events. As explained in Section 3.2, in the period 1992–2008 our data comprise 633 events, namely, more than 600 firms of our sample may have potentially affected by the displacement of a connected inventor.

We start by discussing the estimates of the specification in which the dependent variable of Equation (1) is the number of connected inventor hires at time  $t$ . The estimated coefficients (displayed in Figure 1) show that the number of connected inventor hires has a distinct peak at the time of a connected inventor displacement. The 0.046 increase in the number of connected inventor hires is equivalent to a 0.45-standard-deviation increase (the standard deviation of the number of connected hires in the sample is 0.103; see Table 1).

Next, we verify whether the result displayed in Figure 1 is obtained also when using the number of non-connected inventors hired by the firm at time  $t$  as the dependent variable. The dynamics of the coefficients of interest are reported in Figure A1. The results indicate that non-connected inventor hires are not affected by the displacement of a connected inventor.

Overall, these results are consistent with the hypothesis that firms take advantage of the displacement of a connected inventor to recruit connected knowledgeable labor.

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<sup>15</sup>We use the "eventstudyinteract" Stata routine available at <https://economics.mit.edu/grad/sun20/stata>.

### 4.1.2 Evidence: Innovation

The main goal of this paper is to measure the extent to which access to knowledgeable workers has an impact on firms' innovation. We now turn to estimate the version of Equation (1) in which the number of patent applications is the dependent variable.

Figure 2 plots the baseline  $\beta_\tau$  coefficients. The figure has two important features. First, there is no pretreatment trend in the coefficients, lending support to the validity of our research design. This support is reinforced by the lack of pre-trends in the hiring of connected inventors (Figure 1). The second important feature of Figure 2 is that there is an upward shift in innovation after the displacement of a connected inventor.

Although the pattern in Figure 2 is clear, the individual  $\beta_\tau$  coefficients are not estimated very precisely. It is helpful to offer more formal tests of the null hypothesis that the displacement of a connected inventor has no impact on firms innovation. To increase statistical power we test hypotheses on the average of the  $\beta_\tau$  coefficients over various time intervals, as in Kline (2012). The results are shown in Table 3. The estimated average increase in patent applications over the five years starting with the year of a connected inventor's displacement (i.e., the average of the coefficients on  $\tau = 0, \tau = 1, \tau = 2, \tau = 3$ , and  $\tau = 4$ ) is significant and amounts to 0.096 patent applications. A 0.096 increase in the number of patent applications is equivalent to a 0.27-standard-deviation increase (the standard deviation of the number of patent applications in the sample is 0.35; see Table 1). As discussed above, we control for displacement in LLM and industry, and for industry-specific and LLM-specific trends. However, the results reported in this section are very similar if we do not include these control variables.

## 4.2 IV Estimation

In this section, we provide evidence supporting the main hypothesized channel of knowledge transfer through firm-to-firm labor mobility by estimating IV specifications where we use the displacement of a connected inventor as an instrument for the hire of a connected inventor (in any LLM or industry). This approach assumes that the whole impact of a connected inventor displacement occurs through the connected inventor hire. The underlying concept is that knowledge may be partly embedded in inventors, and firms can then gain access to this knowledge by hiring them. Research exploring the possibility of knowledge transfer through firm-to-firm labor mobility includes Dasgupta (2012), who studies a dynamic general equilibrium model with mobility of workers among countries, in which the long-term dynamic learning process plays a crucial role. In the model, work-

ers learn from their managers and knowledge diffusion takes place through labor flows.<sup>16</sup> In [Combes & Duranton \(2006\)](#)’s theoretical analysis, firms selecting their production site foresee that they can enhance their productivity by poaching workers from other companies.

The implementation of our IV strategy is as follows. Let  $Inventor\ Hire^{conn.}$  denote a dummy variable equal to one in each of the five years following a connected inventor hire, and zero otherwise. The econometric equation is:

$$Y_{jst} = \beta_h Inventor\ Hire^{conn.}_{jt} + \beta_n N_{jt} + \beta_d Displaced_{st} + Trend_{st} + Trend_{lt} + \lambda_j + \alpha_t + u_{jst}. \quad (2)$$

where the dependent variable is the number of patent applications by firm  $j$ . We instrument  $Inventor\ Hire^{conn.}$  with  $Displ.\ Inventor^{conn.}$ , namely, a variable dummy equal to 1 in each of the five years following a connected inventor displacement, and 0 otherwise.

#### 4.2.1 Evidence

In this section, we use the displacement of a connected inventor to instrument the hire of a connected inventor. Table 4 displays the main 2SLS estimates: the first column controls for network size, firm, and time-fixed effects; the second column includes displacement in LLM and industry; and the third column adds industry-specific and LLM-specific trends. The first-stage F-statistics range from 12 to 21. The coefficient of our variable of interest is significant at the 1 percent level. The estimated average increase in the number of patent applications submitted to the EPO over the five years starting with the year of a connected inventor’s hire is 0.6. To put the magnitude of the estimated effect in perspective, we calculate the fraction of overall variation in innovation explained by the hire of a connected inventor. A change of 0.6 patent applications is equivalent to an increase of 1.71 standard deviations (recall that the standard deviation of the number of patent applications in the estimation sample is 0.35). When interpreting these estimates, it is important to keep in mind that, as discussed above, hiring a connected inventor is a major change in terms of workforce for the average firm in our data. We thus believe that this implied shift in the number of patent applications after a connected inventor hire is large but not unrealistic.

In column (4) of Table 4, we restrict the dependent variable to the yearly number of patent submissions that are not authored or co-authored by the newly hired connected inventor. The estimates indicate a 0.325 increase in the patent submissions authored by the other workers of the focal firm, excluding those with a newly hired connected inventor in the team (the result is significant at the 5 percent statistical level). This result suggests

<sup>16</sup>Similar theoretical contributions include studies by [Cooper \(2001\)](#), [Markusen \(2001\)](#), [Glass & Saggi \(2002\)](#), and [Fosfuri, Motta, & Rønde \(2001\)](#).

that hiring an inventor may spur firms' innovation not just through coauthorships, but also through some mechanism of "fertilization".

### 4.3 Validity and Robustness

#### Citation-Weighted Patent Counts

The baseline analysis uses simple patent counts. We now explore the sensitivity of our results when we use citation-weighted patent counts (Griliches, Hall, & Pakes, 1991; Hall, Jaffe, & Trajtenberg, 2005; Dechezleprêtre et al., 2017). In constructing this dependent variable, we employ the truncation correction weights devised by Hall, Jaffe, & Trajtenberg (2001) to correct for systematic citation differences across different technology classes and for the fact that earlier patents will have more years during which they can receive citations. The estimates, shown in Figure A2 and Panel A of Table 5, are qualitatively similar to the baseline estimates. Specifically, the estimated average increase in citation-weighted patent applications in the five years after a connected inventor's displacement is 0.17 standard deviations (the standard deviation of citation-weighted patent applications in the sample is 0.8).

#### A Placebo Exercise

As discussed above, a potential identification concern arises if the shocks to the supply of knowledgeable labor derived from establishment closure also pick up market-level shocks. To further explore this possibility, we perform a "placebo"-type analysis. Specifically, we investigate how innovation at firm  $j$  reacts to the displacement of inventors who are connected to other firms in the same LLM and industry but not to the focal firm  $j$ . Figure A3 and Panel B of Table 5 report the estimates. The estimated average change over the five years starting with the year of the placebo event is non-significant. While we cannot completely rule out the possibility of market effects, the placebo results suggest that the effect identified in the previous section genuinely captures the improved access to inventors through co-worker network connections.

#### Never Treated as the Control Cohort

For the main analysis, we use the last cohort as the control cohort. Figure A4 and Panel C of Table 5 report the estimates using the never treated as the control cohort. The estimates are qualitatively very similar to the baseline estimates.

#### Conventional TWFE event study design

For the main analysis, we use the interaction-weighted estimator. Figure A5 and the first row of Panel D of Table 5 report the coefficients estimated using a conventional TWFE

event study design. Specifically, this approach compares changes in patent applications of firms that experience the displacement of a connected inventor both to firms that have yet to experience such an event and to firms that will never do so during our sample period. In Figure A6 and the second row of Panel D, we drop the never-treated firms, and therefore identification originates from the differential timing of treatment onset among the treated firms. Both sets of results are qualitatively similar to the baseline results.

### Connected and Non-Connected Inventor Hires

Firms may hire non-connected inventors in addition to or in place of those who are connected. Motivated by this observation, we enrich Equation 2 by adding non-connected inventor hires among the explanatory variables. Such a specification is relevant for two reasons. First, it tells us how the coefficient on connected inventor hiring changes once we take into account the non-connected inventor hires. Second, it is useful to compare the coefficients of connected and non-connected inventor hiring. Hence we estimate the following equation:

$$Y_{jst} = \beta_{hc} \text{Inv hire}^{conn.}_{jt} + \beta_{hnc} \text{Inv hire}^{nonconn.}_{jt} + \delta_1 N_{jt} + \delta_2 \text{Displaced}_{slt} + T_{st} + T_{lt} + \lambda_j + \alpha_t + u_{jst}. \quad (3)$$

where  $\text{Inventor Hire}^{nonconn.}$  is a dummy equal to one in each of the five years following a non-connected inventor hire, and zero otherwise. As in the previous section, we instrument  $\text{Inventor Hire}^{conn.}$  with  $\text{Displ. Inventor}^{conn.}$ .

The estimates of this specification are shown in the first column of Table A1. The coefficient on  $\text{Inventor Hire}^{conn.}$  is significant and very similar to the estimates reported in columns (1)–(3) of Table 4, while the coefficient on  $\text{Inventor Hire}^{nonconn.}$  is non-significant. We reject the null hypothesis of equality of the two coefficients.

A potential concern is the possible endogeneity of non-connected inventors hires. Therefore, we instrument  $\text{Inventor Hire}^{nonconn.}$  with  $\text{Displ. Inventor}^{nonconn.}$ , namely, a dummy equal to one in each of the five years following a non-connected inventor displacement and zero otherwise. We impose that such a displacement must originate from a closure within the same industry of firm  $j$ ; otherwise, the dummy would always be equal to one (Table 2). The estimates, shown in the second column of Table A1, indicate that the coefficient of  $\text{Inventor Hire}^{conn.}$  is significant (with a magnitude similar to the baseline specification), while the 2SLS coefficient of  $\text{Inventor Hire}^{nonconn.}$  is not significant (with a first-stage F-statistic of 14.18). We reject the null hypothesis of equality of the two coefficients ( $\text{Inventor Hire}^{conn.}$  and  $\text{Inventor Hire}^{nonconn.}$ ). The estimated increase in the number of patent applications due to an additional connected inventor is 0.7. Overall, our results suggest that connections are particularly important to spur innovation, possi-

bly because hiring through connections helps firms to lower information asymmetries and thus employ better-quality inventors.

It is instructive to compare the specification of the second column of Table A1 (two endogenous variables in 2SLS) with the OLS version in which *Inventor Hire<sup>conn.</sup>* and *Inventor Hire<sup>nonconn.</sup>* are not instrumented. The OLS estimates are shown in the third column of Table A1, whereby both the coefficients on *Inventor Hire<sup>conn.</sup>* and *Inventor Hire<sup>nonconn.</sup>* are positive and significant (a statistical test fails to reject that the coefficients are equal).

Column 3 of Table A1 also reports the p-values for the test of equality between the OLS and IV coefficients. The entries indicate that the *Inventor Hire<sup>conn.</sup>* coefficient in the third specification (equal to 0.12) is statistically different from the corresponding IV coefficient (0.70), while the *Inventor Hire<sup>nonconn.</sup>* coefficient is not statistically different. A possible explanation for the difference between the IV and OLS coefficient of *Inventor Hire<sup>conn.</sup>* is that the effect of connected inventors may be heterogeneous across firms. If there are indeed heterogeneous effects of connected inventors on innovation, then consistent OLS measures the average effect of connected inventor hiring on patenting across all firms. On the other hand, 2SLS estimates the average effect for firms that are marginal in the recruitment decision. Specifically, this describes firms that recruit connected inventors if and only if there exists excess "directed" local supply, namely, if and only if they experience the event of the displacement of a connected inventor.<sup>17</sup> If the effect of connected inventors on patenting is larger for firms that are marginal in the recruitment decision, the 2SLS estimates will exceed those of consistent OLS.

## 5 Concluding Remarks

A prominent feature of the labor market in many developed countries is the tendency of firms to hire through social connections. Nevertheless, we have very limited knowledge of the extent to which available connections have an impact on firms' innovation. The central empirical goal of this paper is to measure the extent to which access to knowledgeable workers fosters innovation. The displacement of inventors due to establishment closures generates labor supply shocks to firms that employ their previous co-workers. Our estimates indicate that firms exploit the opportunity offered by such displacements to recruit connected inventors. Moreover, the improved capacity to employ connected inventors increases firms' patenting activity.

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<sup>17</sup>See [Imbens & Angrist \(1994\)](#) for a discussion. For examples of applications, see [Eisensee & Strömberg \(2007\)](#) and [Serafinelli \(2019\)](#).

## References

- Akcigit, U., S. Baslandze, & F. Lotti (2023). Connecting to power: political connections, innovation, and firm dynamics. *Econometrica* 91(2), 529–564.
- Autor, D. H. (2003). Outsourcing at will: The contribution of unjust dismissal doctrine to the growth of employment outsourcing. *Journal of labor economics* 21(1), 1–42.
- Azoulay, P., C. Fons-Rosen, & J. S. Graff Zivin (2019). Does science advance one funeral at a time? *American Economic Review* 109(8), 2889–2920.
- Balsvik, R. (2011). Is labor mobility a channel for spillovers from multinationals? evidence from norwegian manufacturing. *Review of Economics and Statistics* 93(1), 285–297.
- Bandiera, O., I. Barankay, & I. Rasul (2010). Social incentives in the workplace. *The Review of Economic Studies* 77(2), 417–458.
- Battisti, M., G. Peri, & A. Romiti (2016). Dynamic effects of co-ethnic networks on immigrants' economic success. Technical report, National Bureau of Economic Research.
- Beaman, L. & J. Magruder (2012). Who gets the job referral? evidence from a social networks experiment. *American Economic Review* 102(7), 3574–3593.
- Becattini, G., M. Bellandi, & L. De Propriis (2014). *A handbook of industrial districts*. Edward Elgar Publishing.
- Bell, A., R. Chetty, X. Jaravel, N. Petkova, & J. Van Reenen (2019). Who becomes an inventor in america? the importance of exposure to innovation. *The Quarterly Journal of Economics* 134(2), 647–713.
- Bloom, N., M. Schankerman, & J. Van Reenen (2013). Identifying technology spillovers and product market rivalry. *Econometrica* 81(4), 1347–1393. Available from: <http://dx.doi.org/10.3982/ECTA9466>, doi:10.3982/ECTA9466.
- Breschi, S. & F. Lissoni (2001). Knowledge spillovers and local innovation systems: a critical survey. *Industrial and corporate change* 10(4), 975–1005.
- Brusco, S. (1983). The emilian model: Productive decentralisation and social integration. *Cambridge Journal of Economics* 6(2), 167–184.
- Burks, S. V., B. Cowgill, M. Hoffman, & M. Housman (2015). The value of hiring through employee referrals. *The Quarterly Journal of Economics* 130(2), 805–839.

- Cestone, G., C. Fumagalli, F. Kramarz, & G. Pica (2016). Insurance between firms: The role of internal labor markets. *Centre for Economic Policy Research DP* (11336).
- Cingano, F. & A. Rosolia (2012). People I Know: Job Search and Social Networks. *Journal of Labor Economics* 30(2), 291–332.
- Colussi, T. (2018). Social ties in academia: A friend is a treasure. *Review of Economics and Statistics* 100(1), 45–50.
- Combes, P. P. & G. Duranton (2006, January). Labour pooling, labour poaching, and spatial clustering. *Regional Science and Urban Economics* 36(1), 1–28.
- Cooper, D. P. (2001). Innovation and reciprocal externalities: Information transmission via job mobility. *Journal of Economic Behavior and Organization* 45(4), 403–425.
- Cornelissen, T., C. Dustmann, & U. Schönberg (2017). Peer effects in the workplace. *American Economic Review* 107(2), 425–456.
- Crescenzi, R. & L. Gagliardi (2018). The innovative performance of firms in heterogeneous environments: The interplay between external knowledge and internal absorptive capacities. *Research Policy* 47(4), 782–795.
- Dasgupta, K. (2012). Learning and knowledge diffusion in a global economy. *Journal of International Economics* 87(2), 323–336.
- De Blasio, G. & S. Di Addario (2005). Do workers benefit from industrial agglomeration? evidence from displaced workers. *Journal of Regional Science* 45(4), 797—827.
- Dechezleprêtre, A., R. Martin, & M. Mohnen (2017). Knowledge spillovers from clean and dirty technologies. *Grantham Research Institute on Climate Change and the Environment Working Paper No. 135*.
- Depalo, D. & S. L. Di Addario (2014). Shedding light on inventors’ returns to patents. *Development Studies Working Papers*, Centro Studi Luca d’Agliano (375).
- Di Addario, S. L. & A. Wu (2024). Who becomes an inventor? the role of firms in talent discovery. *mimeo*.
- Diegmann, A., L. Pohlen, & A. Weber (2024). Do politicians affect firm outcomes? evidence from connections to the german federal parliament. *CEPR Discussion Paper No. DP19119*.
- Dustmann, C., A. Glitz, U. Schönberg, & H. Brücker (2016). Referral-based job search networks. *The Review of Economic Studies* 83(2), 514–546.

- Eisensee, T. & D. Strömberg (2007). News droughts, news floods, and u.s. disaster relief. *The Quarterly Journal of Economics* 122(2), 693–728.
- Eliason, M., L. Hensvik, F. Kramarz, & O. N. Skans (2017). The causal impact of social connections on firms’ outcomes. *CEPR Discussion Paper No. DP12135*.
- Eliason, M., L. Hensvik, F. Kramarz, & O. N. Skans (2023). Social connections and the sorting of workers to firms. *Journal of Econometrics* 233(2), 468–506.
- Fons-Rosen, C. (2013). Knowledge flows through fdi: the case of privatisations in central and eastern europe. *Mimeograph Universitat Pompeu Fabra*.
- Fons-Rosen, C., S. Kalemli-Ozcan, B. E. Sorensen, C. Villegas-Sanchez, & V. Volosovych (2017). Foreign investment and domestic productivity: Identifying knowledge spillovers and competition effects. Technical report, National Bureau of Economic Research.
- Fons-Rosen, C., V. Scrutinio, & K. Szemerédi (2016). Colocation and knowledge diffusion: evidence from million dollar plants.
- Fosfuri, A., M. Motta, & T. Rønde (2001). Foreign direct investment and spillovers through workers’ mobility. *Journal of International Economics* 53(1), 205–222.
- Friebel, G., M. Heinz, M. Hoffman, & N. Zubanov (2019). What do employee referral programs do? Technical report, National Bureau of Economic Research.
- Ganguli, I., J. Lin, & N. Reynolds (2020). The paper trail of knowledge spillovers: evidence from patent interferences. *American Economic Journal: Applied Economics* 12(2), 278–302.
- Gathmann, C., I. Helm, & U. Schönberg (2020). Spillover effects of mass layoffs. *Journal of the European Economic Association* 18(1), 427–468.
- Glass, A. & K. Saggi (2002). Multinational firms and technology transfer. *The Scandinavian Journal of Economics* 104(4), 495–513.
- Glitz, A. (2017). Coworker networks in the labour market. *Labour Economics* 44(C), 218–230.
- Glitz, A. & R. Vejlin (2021). Learning through coworker referrals. *Review of Economic Dynamics* 42, 37–71.

- Griliches, Z., B. H. Hall, & A. Pakes (1991). R&d, patents, and market value revisited: is there a second (technological opportunity) factor? *Economics of Innovation and new technology* 1(3), 183–201.
- Hall, B. H., A. Jaffe, & M. Trajtenberg (2005). Market value and patent citations. *The RAND Journal of Economics* 36(1), 16–38.
- Hall, B. H., A. B. Jaffe, & M. Trajtenberg (2001). The nber patent citation data file: Lessons, insights and methodological tools. Technical report, National Bureau of Economic Research.
- Hall, B. H., F. Lotti, & J. Mairesse (2008). Employment, innovation, and productivity: evidence from italian microdata. *Industrial and corporate change* 17(4), 813–839.
- Henry, N. & S. Pinch (2000). Spatialising knowledge: placing the knowledge community of motor sport valley. *Geoforum* 31(2), 191–208.
- Hensvik, L. & O. N. Skans (2016). Social Networks, Employee Selection, and Labor Market Outcomes. *Journal of Labor Economics* 34(4), 825–867.
- Huang, K., E. Moretti, & X. Xia (2023). Local innovation through investment in education: Evidence from chinese cities. *Mimeograph*.
- Imbens, G. W. & J. D. Angrist (1994). Identification and estimation of local average treatment effects. *Econometrica* 62(4), 467–476.
- Jaravel, X., N. Petkova, & A. Bell (2018). Team-specific capital and innovation. *American Economic Review* 108(4-5), 1034–73.
- Kaiser, U., H. C. Kongsted, & T. Rønde (2015). Does the mobility of r&d labor increase innovation? *Journal of Economic Behavior & Organization* 110, 91–105.
- Kantor, S. & A. Whalley (2014). Knowledge spillovers from research universities: evidence from endowment value shocks. *Review of Economics and Statistics* 96(1), 171–188.
- Kline, P. (2012). The impact of juvenile curfew laws on arrests of youth and adults. *American Law and Economics Review* 14(1), 44–67.
- Kline, P., N. Petkova, H. Williams, & O. Zidar (2019). Who profits from patents? rent-sharing at innovative firms. *The Quarterly Journal of Economics* 134(3), 1343–1404.
- Kramarz, F. & O. N. Skans (2014). When strong ties are strong: Networks and youth labour market entry. *Review of Economic Studies* 81(3), 1164–1200.

- Maliranta, M., P. Mohnen, & P. Rouvinen (2009). Is inter-firm labor mobility a channel of knowledge spillovers? evidence from a linked employer-employee panel. *Industrial and Corporate Change* 18(6), 1161–1191.
- Marin, G. & F. Lotti (2016). Productivity effects of eco-innovations using data on eco-patents. *Industrial and corporate change*, dtw014.
- Markusen, J. (2001). Contracts, intellectual property rights, and multinational investment in developing countries. *Journal of International Economics* 53(1), 189–204.
- Marshall, A. (1890). *Principle of Economics*. McMillan and co., London, 8th ed.
- Mas, A. & E. Moretti (2009). Peers at work. *American Economic Review* 99, 112–145.
- Mohnen, M. (2022). Stars and brokers: Knowledge spillovers among medical scientists. *Management Science* 68(4), 2513–2532.
- Moretti, E. (2021). The effect of high-tech clusters on the productivity of top inventors. *American Economic Review* 111(10), 3328–3375.
- Moser, P., A. Voena, & F. Waldinger (2014). German jewish émigrés and us invention. *American Economic Review* 104(10), 3222–55.
- Parrotta, P. & D. Pozzoli (2012). The effect of learning by hiring on productivity. *The RAND Journal of Economics* 43(1), 167–185.
- Pellizzari, M. (2010). Do friends and relatives really help in getting a good job? *ILR Review* 63(3), 494–510.
- Piore, M. & C. Sabel (1984). Italian small business development: Lessons for u.s. industrial policy. *American Industry in International Competition*. Cornell University Press John Zysman and Laura Tyson (eds.).
- Poole, J. P. (2013). Knowledge transfers from multinational to domestic firms: evidence from worker mobility. *Review of Economics and Statistics* 95(2), 393–406.
- Saxenian, A. (1994). *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Harvard University Press.
- Saygin, P. O., A. Weber, & M. A. Weynandt (2019). Coworkers, networks, and job-search outcomes among displaced workers. *ILR Review*, 0019793919881988.
- Schmutte, I. M. (2015). Job referral networks and the determination of earnings in local labor markets. *Journal of Labor Economics* 33(1), 1–32.

- Serafinelli, M. (2019). “good” firms, worker flows, and local productivity. *Journal of Labor Economics* 37(3), 747–792.
- Stoyanov, A. & N. Zubanov (2012). Productivity spillovers across firms through worker mobility. *American Economic Journal: Applied Economics* 4(2), 168–198.
- Sun, L. & S. Abraham (2021). Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. *Journal of Econometrics* 225(2), 175–199.
- Tattara, G. & M. Valentini (2010). Turnover and excess worker reallocation. the veneto labour market between 1982 and 1996. *Labour* 24(4), 474–500.
- Topa, G. (2011). Labor markets and referrals. In *Handbook of social economics*, Volume 1, pp. 1193–1221. Elsevier.
- Trigilia, C. (1990). Work and politics in the third italy’s industrial districts. *Industrial Districts and Inter-Firm Co-operation in Italy, Geneva: International Institute for Labor Studies F. Pyke, G. Becattini and W. Sengenberger (eds.)*, 160–184.
- Trigilia, C. (2020). Innovazione e territorio. *Podcast DIST - Lezioni Italiane, Puntata 5*.
- Waldinger, F. (2010). Quality matters: The expulsion of professors and the consequences for phd student outcomes in nazi germany. *Journal of Political Economy* 118(4), 787–831.
- Waldinger, F. (2012). Peer effects in science: Evidence from the dismissal of scientists in nazi germany. *The Review of Economic Studies* 79(2), 838–861.
- Wang, S.-Y. (2013). Marriage networks, nepotism, and labor market outcomes in china. *American Economic Journal: Applied Economics* 5(3), 91–112.
- Whitford, J. (2001). The decline of a model? challenge and response in the italian industrial districts. *Economy and Society* 30(1), 38–65.
- Zacchia, P. (2020). Knowledge spillovers through networks of scientists. *The Review of economic studies* 87(4), 1989–2018.

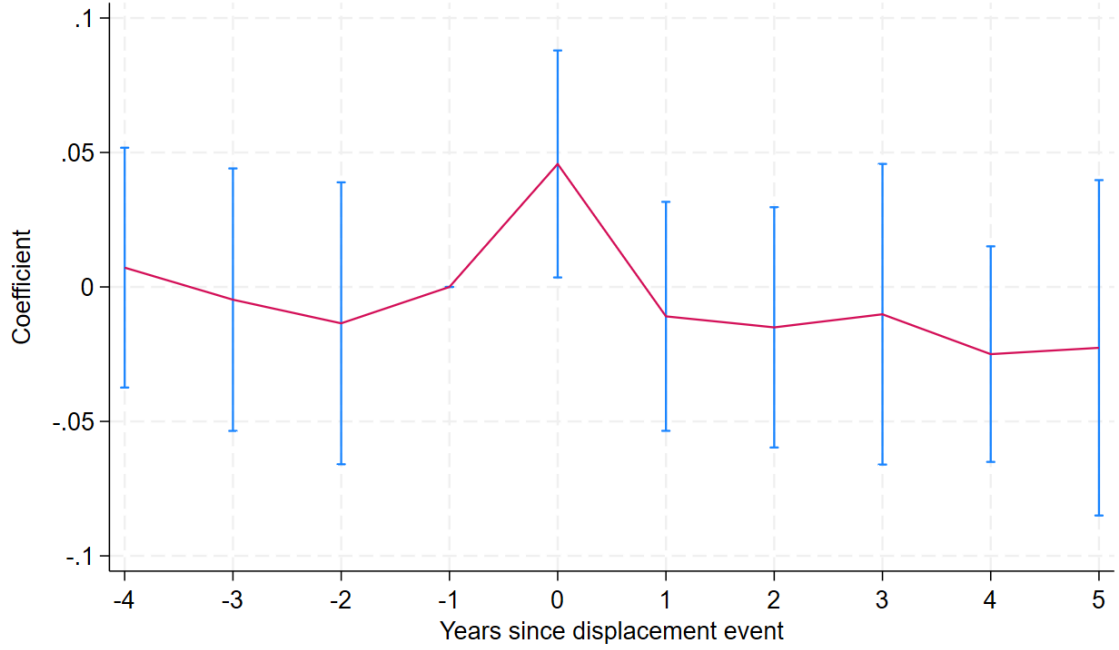


FIGURE 1. Connected inventor hires, relative to the year of a connected inventor displacement. The figure plots point estimates of leading and lagging indicators for the displacement of a connected inventor using the interaction-weighted estimator (Sun and Abraham, 2021). The dependent variable is the number of connected inventor hires (from any industry or LLM) for firm  $j$  of industry  $s$  and local labor market (LLM)  $l$  at time  $t$ . Event time indicator " $-4$ " is set to 1 for periods up to and including 4 periods prior to the event and 0 otherwise. Event time indicator " $+5$ " is set to 1 for all periods successively following the fifth year after the event, and 0 otherwise. The control cohort is taken as the last cohort. The period prior to the event is omitted. The bands around the point estimates are 95 percent cluster-robust confidence intervals, with LLM used as the clustering level.

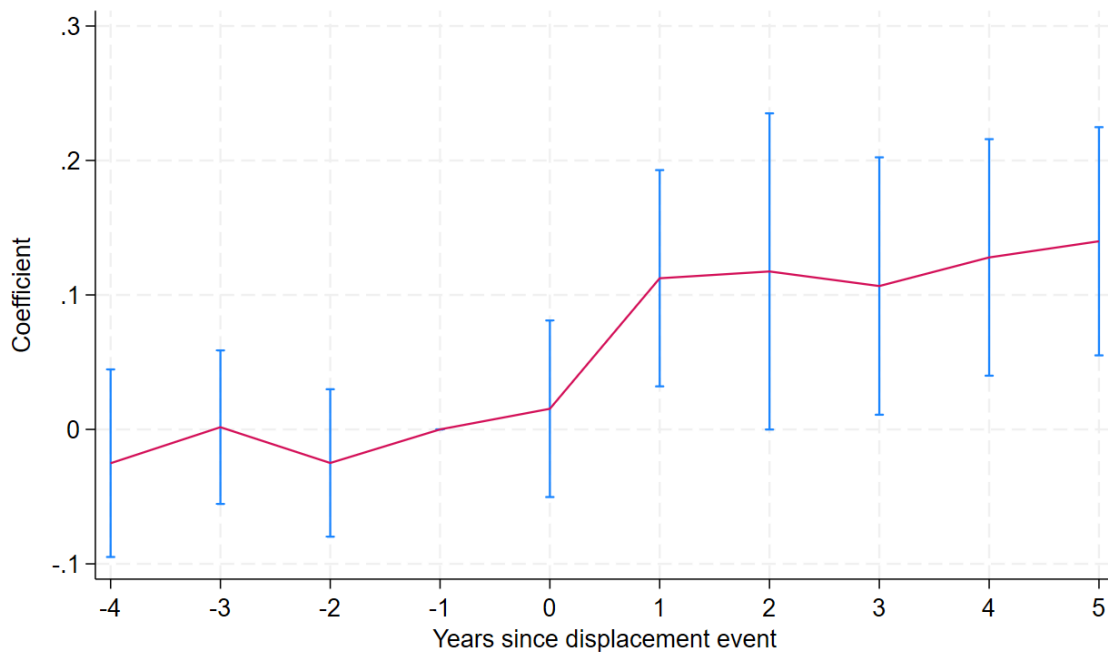


FIGURE 2. Patent applications, relative to the year of a connected inventor displacement. The figure plots point estimates of leading and lagging indicators for the displacement of a connected inventor using the interaction-weighted estimator (Sun and Abraham, 2021). The dependent variable is the number of patent applications. Event time indicator " $-4$ " is set to 1 for periods up to and including 4 periods prior to the event and 0 otherwise. Event time indicator " $+5$ " is set to 1 for all periods successively following the fifth year after the event, and 0 otherwise. The period prior to the event is omitted. The control cohort is taken as the last cohort. The bands around the point estimates are 95 percent cluster-robust confidence intervals, with LLM used as the clustering level.

TABLE 1. Summary statistics for the estimation sample (1992–2008).

	Mean	SD	Min	Max
<i>No. of Patent Applications</i>	0.038	0.354	0	20
<i>Inventor Hires<sup>conn.</sup></i>	0.008	0.103	0	7
<i>Inventor Hires<sup>nonconn.</sup></i>	0.004	0.137	0	31
<i>Employees</i>	47.413	70.404	6	499
<i>Firm Network</i>	865.692	1,226.655	1	23,233
<i>Displaced Inventors<sup>conn.</sup></i>	0.011	0.203	0	35
<i>Displaced Non-Inventors<sup>conn.</sup></i>	2.934	14.119	0	510

Note: The sample contains 84,173 observations for 7,666 firms. The table reports unweighted means. *No. of Patent Applications* is the average number of patent applications submitted by the firms in the sample. *Inventor Hires<sup>conn.</sup>* is the number of connected inventor hires. *Inventor Hires<sup>nonconn.</sup>* is the number of non-connected inventor hires. *Employees* is the average number of employees employed by the firms in the sample. *Firm Network* is the number of former co-workers of current employees. *Displaced Inventors<sup>conn.</sup>* is the number of connected inventors who are displaced in a given year. *Displaced Non-Inventors<sup>conn.</sup>* is the number of connected non-inventors who are displaced in a given year.

TABLE 2. Numbers of Events, displacements, and hires by year

Year	Events	Displaced inventors	Displaced non-inventors	Connected inventor hires	Non-connected inventor hires
1992	30	5	3,239	16	1
1993	28	17	4,236	16	5
1994	5	7	2,793	16	5
1995	1	9	3,471	31	11
1996	21	51	5,489	39	18
1997	23	24	22,063	27	12
1998	64	29	5,074	34	86
1999	19	10	8,767	26	31
2000	16	12	3,500	55	28
2001	77	43	6,272	54	11
2002	37	21	4,687	50	17
2003	62	17	5,381	53	25
2004	96	62	4,490	67	23
2005	90	35	6,037	49	25
2006	23	36	8,173	51	10
2007	23	36	6,221	47	18
2008	18	33	5,426	51	17
Total	633	447	105,319	682	343

TABLE 3. Connected inventor displacements and patent applications—event study.

Dependant variable: <i>No. Patent applications</i>	$\tau = 0$	$\tau \in [1, 2]$	$\tau \in [3, 4]$	$\tau \in [0, 4]$
	0.015 (0.033)	0.115** (0.047)	0.117*** (0.045)	0.096** (0.040)

Note: Estimates refer to Equation (1) whereby the dependent variable is the number of patent applications. The table corresponds to Figure 2. The sample size is 7,232 (624 firms). The reduced sample size compared with Table 1 stems from the fact that the analysis sample excludes the never-treated and is before the treated periods for the last-treated cohort. Samples include only firms with more than five observations in the period of interest. The model includes year and firm fixed effects, industry and LLM trends, network size, and the number of displaced workers in the  $\text{LLM} \times \text{industry} \times \text{year}$ . Numbers in parentheses are standard errors clustered at the LLM level.  $\tau \in [a, b]$  refers to the average of the coefficients between period  $\tau = a$  and period  $\tau = b$ . \* $p < 0.1$ , \*\*  $p < 0.05$ , and \*\*\*  $p < 0.01$ .

TABLE 4. Connected inventor hires and patent applications—2SLS estimates

Dependent variable	All patent applications			W/o conn. hires
	(1)	(2)	(3)	(4)
Panel A: 2SLS estimates				
<i>Inventor Hire<sup>conn.</sup></i>	0.622*** (0.191)	0.622*** (0.190)	0.681*** (0.252)	0.325** (0.165)
<i>F-stat, 1<sup>st</sup> stage</i>	21.16	21.17	12.06	12.06
<i>No. obs.</i>	80, 121	80, 121	80, 121	80, 121
<i>Displaced<sub>slt</sub></i>	-	+	+	+
<i>Industry and LLM Trends</i>	-	-	+	+
Panel B: First stage estimates				
<i>Displ. Inventor<sup>conn.</sup></i>	0.060*** (0.013)	0.060*** (0.013)	0.049*** (0.014)	0.049*** (0.014)
Panel C: Reduced form estimates				
<i>Displ. Inventor<sup>conn.</sup></i>	0.037*** (0.009)	0.037*** (0.009)	0.033*** (0.009)	0.016* (0.009)

Note: Estimates refer to Equation (2). In columns (1)–(3), the dependent variable is the number of patent applications, while in column (4) it is the number of patent submissions excluding those authored or co-authored by the newly hired connected inventor(s). The estimation sample includes only firms with more than five observations in the period of interest. Numbers in parentheses are standard errors clustered at the LLM level. Network size, firm, and time-fixed effects are always included. *Displaced<sub>slt</sub>* denotes the number of displaced workers in the same LLM  $\times$  industry  $\times$  year. \* $p < 0.1$ , \*\*  $p < 0.05$ , and \*\*\*  $p < 0.01$ .

TABLE 5. Citation-weighted patent counts, placebo, never treated as control cohort, and conventional TWFE event study design

Panel A: Citation-weighted patent counts				
Dependant variable: <i>No. Citation-Weighted Patent Ap- plications</i>	$\tau = 0$	$\tau \in [1, 2]$	$\tau \in [3, 4]$	$\tau \in [0, 4]$
	-0.105 (0.079)	0.241*** (0.080)	0.141** (0.060)	0.132** (0.054)
Panel B: Placebo				
Dependant variable: <i>No. Patent Applications</i>	$\tau = 0$	$\tau \in [1, 2]$	$\tau \in [3, 4]$	$\tau \in [0, 4]$
	0.009 (0.011)	-0.008 (0.012)	-0.024 (0.017)	-0.011 (0.010)
Panel C: Never treated as control cohort				
Dependant variable: <i>No. Patent Applications</i>	$\tau = 0$	$\tau \in [1, 2]$	$\tau \in [3, 4]$	$\tau \in [0, 4]$
	-0.017 (0.022)	0.067*** (0.015)	0.037** (0.019)	0.038*** (0.014)
Panel D: Conventional TWFE event study design				
Dependant variable: <i>No. Patent Applications</i>	$\tau = 0$	$\tau \in [1, 2]$	$\tau \in [3, 4]$	$\tau \in [0, 4]$
<i>Baseline Sample</i>	-0.013 (0.025)	0.066*** (0.021)	0.046** (0.019)	0.042*** (0.014)
<i>Treated Only</i>	-0.005 (0.023)	0.074*** (0.024)	0.066** (0.026)	0.055*** (0.019)

Note: Estimates refer to Equation (1). In Panel A, the dependent variable is the number of citation-weighted patent applications. In Panels B, C, and D, the dependent variable is the number of patent applications. The sample size is 7,232 (624 firms) in Panel A, 27,175 (4,139 firms) in Panel B, 81,055 (7,381 firms) in Panel C, 81,059 (7,385 firms) in *Baseline Sample* in Panel D, and lowered to 7,609 (628 firms) for the *Treated only* sub-sample. Estimation samples include only firms with more than five observations. The model includes year and firm fixed effects, industry and LLM trends, network size, and the number of displaced workers in the  $LLM \times industry \times year$ . Numbers in parentheses are standard errors clustered at the LLM level.  $\tau \in [a, b]$  refers to the average of the coefficients between period  $\tau = a$  and period  $\tau = b$ . \* $p < 0.1$ , \*\* $p < 0.05$ , and \*\*\* $p < 0.01$ .

## Appendix

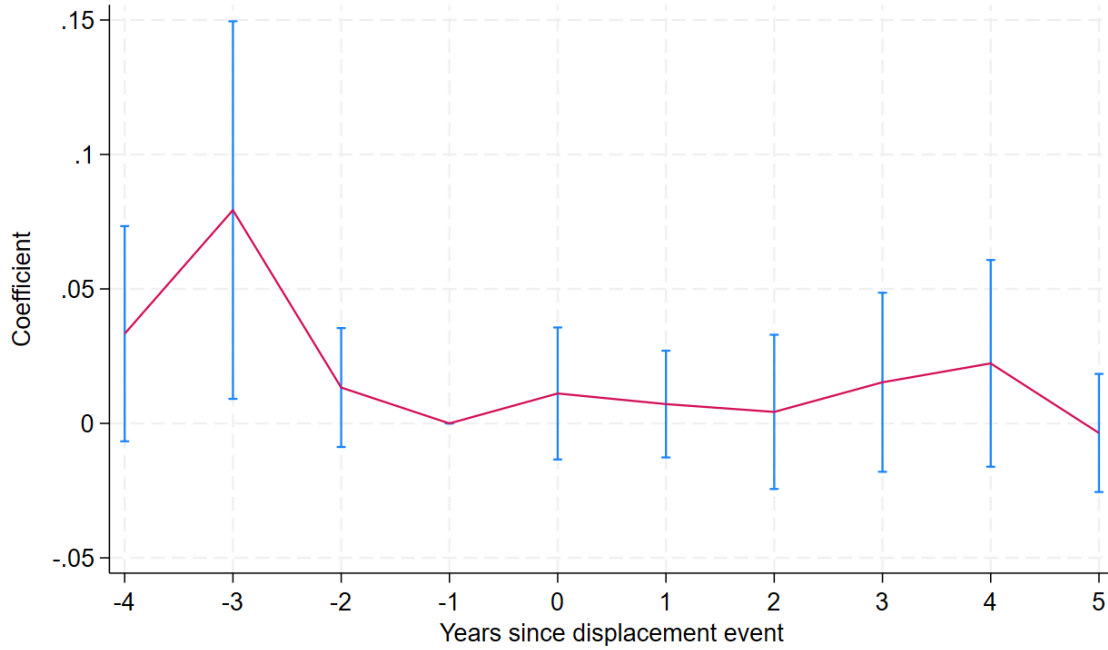


FIGURE A1. Non-connected inventor hires, relative to the year of a connected inventor displacement. The figure plots point estimates of the leading and lagging indicators for the displacement of a connected inventor using the interaction-weighted estimator (Sun and Abraham, 2021). The dependent variable is the number of non-connected inventor hires (from any industry or LLM) for firm  $j$  of industry  $s$  and local labor market (LLM)  $l$  at time  $t$ . Event time indicator " $-4$ " is set to 1 for periods up to and including 4 periods prior to the event and 0 otherwise. Event time indicator " $+5$ " is set to 1 for all periods successively following the fifth year after the event, and 0 otherwise. The period prior to the event is omitted. The control cohort is taken as the last cohort. The bands around the point estimates are 95 percent cluster-robust confidence intervals, with LLM used as the clustering level.

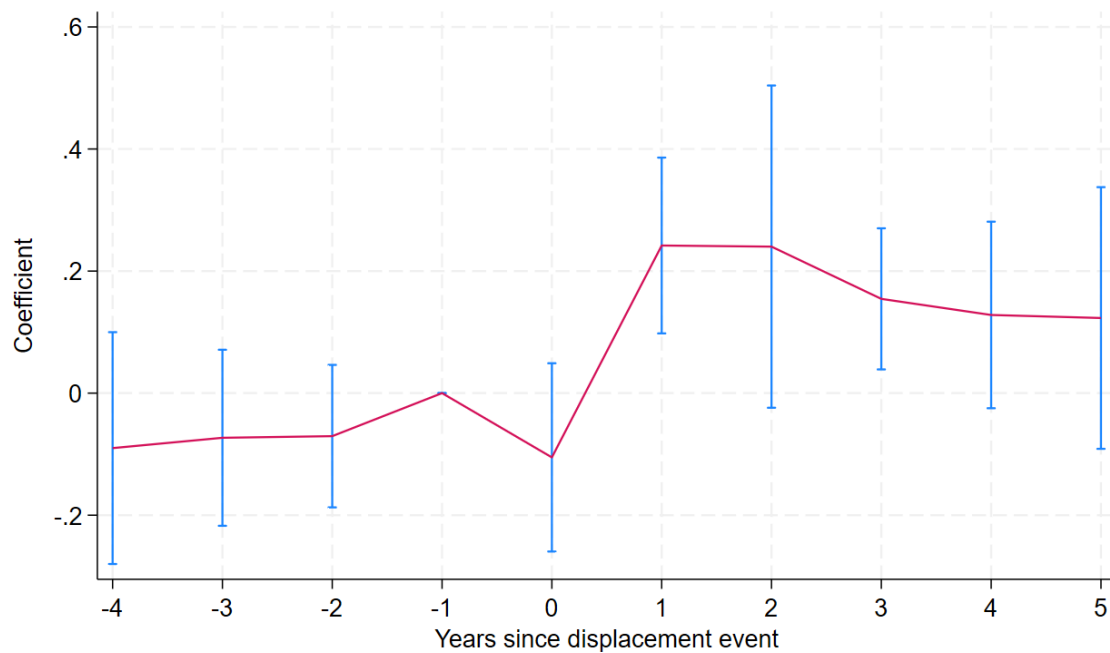


FIGURE A2. Citation-weighted patent applications, relative to the year of a connected inventor displacement. The figure plots point estimates of the leading and lagging indicators for the displacement of a connected inventor using the interaction-weighted estimator (Sun and Abraham, 2021). The dependent variable is the number of citation-weighted patent applications. Event time indicator "-4" is set to 1 for periods up to and including 4 periods prior to the event and 0 otherwise. Event time indicator "+5" is set to 1 for all periods successively following the fifth year after the event, and 0 otherwise. The period prior to the event is omitted. The control cohort is taken as the last cohort. The bands around the point estimates are 95 percent cluster-robust confidence intervals, with LLM used as the clustering level.

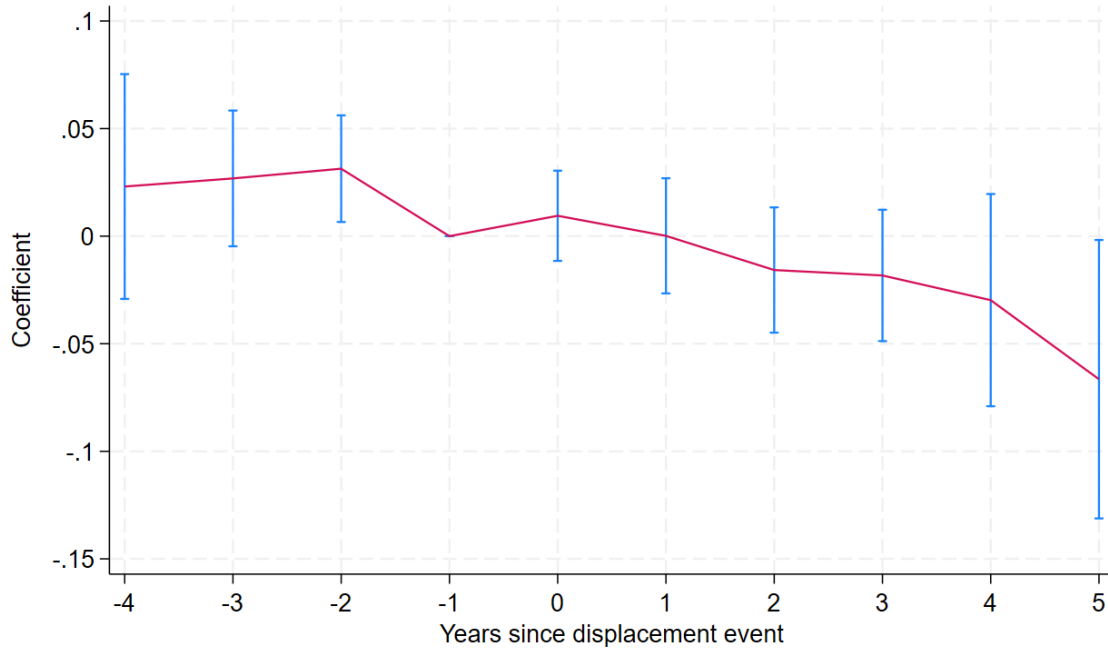


FIGURE A3. Patent applications, relative to the year of a connected inventor displacement—Placebo. The figure plots point estimates of the leading and lagging indicators for the displacement of inventors who are connected to other firms in the same LLM and industry but not to the focal firm  $j$  using the interaction-weighted estimator (Sun and Abraham, 2021). The dependent variable is the number of patent applications. Event time indicator " $-4$ " is set to 1 for periods up to and including 4 periods prior to the event and 0 otherwise. Event time indicator " $+5$ " is set to 1 for all periods successively following the fifth year after the event, and 0 otherwise. The period prior to the event is omitted. The control cohort is taken as the last cohort. The bands around the point estimates are 95 percent cluster-robust confidence intervals, with LLM used as the clustering level.

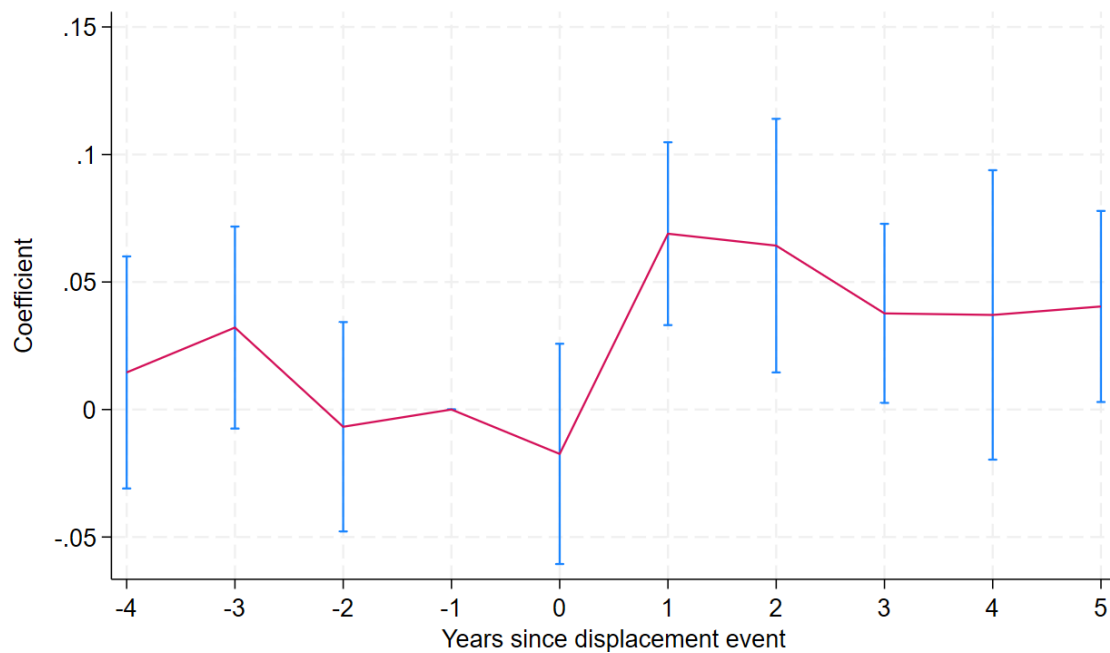


FIGURE A4. Patent applications, relative to the year of a connected inventor displacement—never treated used as the control cohort. The figure plots point estimates of the leading and lagging indicators for the displacement of a connected inventor using the interaction-weighted estimator (Sun and Abraham, 2021). The dependent variable is the number of patent applications. Event time indicator "−4" is set to 1 for periods up to and including 4 periods prior to the event and 0 otherwise. Event time indicator "+5" is set to 1 for all periods successively following the fifth year after the event, and 0 otherwise. The period prior to the event is omitted. The control cohort is taken as the never treated. The bands around the point estimates are 95 percent cluster-robust confidence intervals, with LLM used as the clustering level

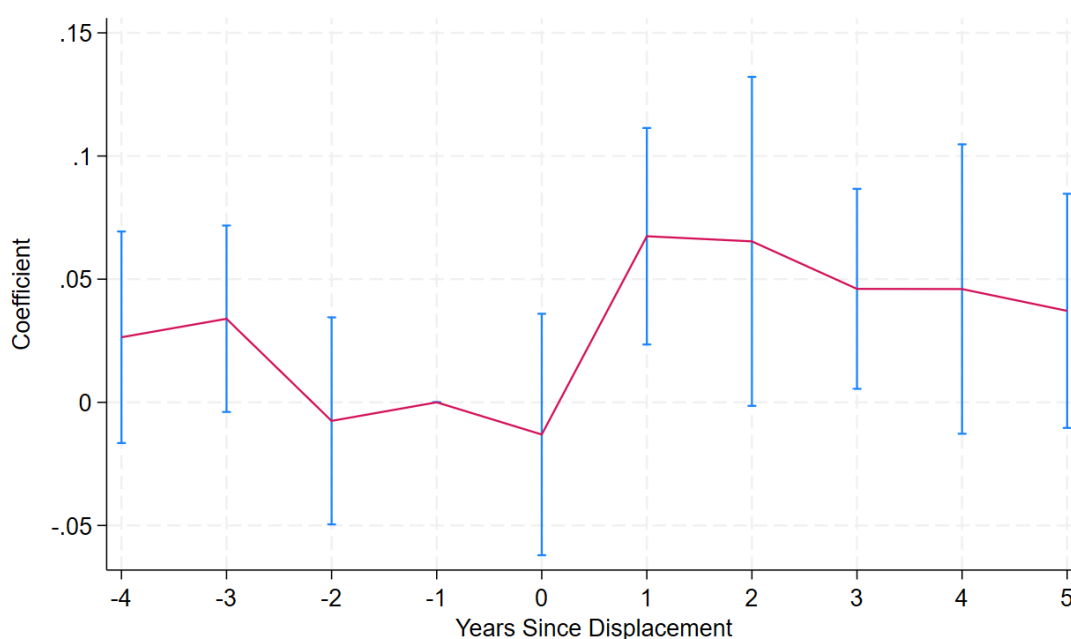


FIGURE A5. Patent applications, relative to the year of a connected inventor displacement—conventional TWFE. The figure plots point estimates of the leading and lagging indicators for the displacement of a connected inventor using a conventional TWFE event study design. The dependent variable is the number of patent applications. Event time indicator "−4" is set to 1 for periods up to and including 4 periods prior to the event and 0 otherwise. Event time indicator "+5" is set to 1 for all periods successively following the fifth year after the event, and 0 otherwise. The period prior to the event is omitted. The bands around the point estimates are 95 percent cluster-robust confidence intervals, with LLM used as the clustering level is LLM

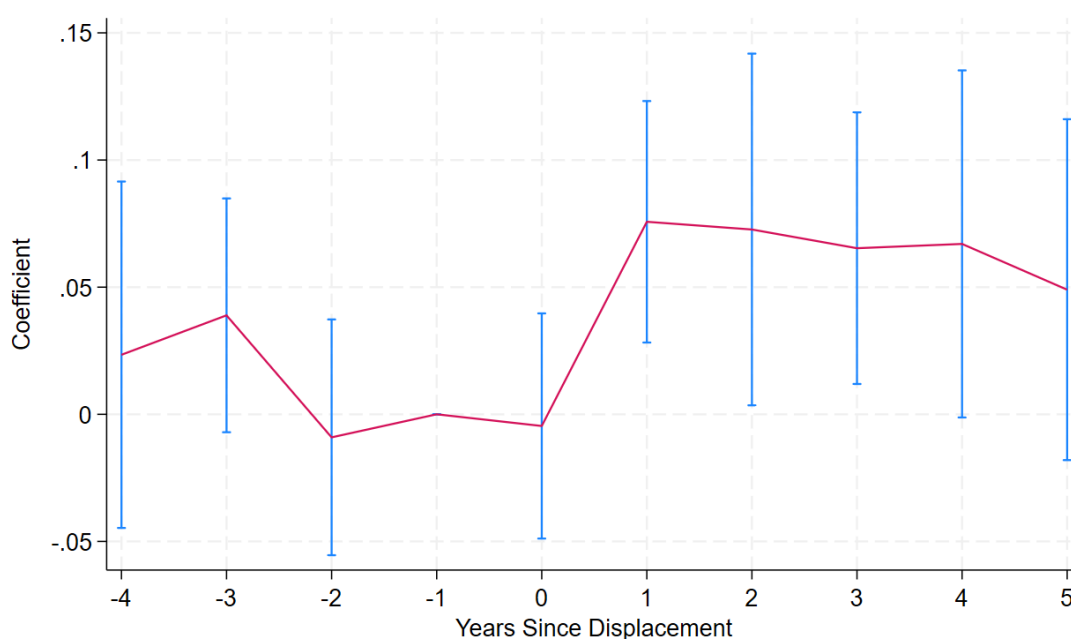


FIGURE A6. Patent applications, relative to the year of a connected inventor displacement—conventional TWFE and treated firms Only. The figure plots point estimates of the leading and lagging indicators for the displacement of a connected inventor using a conventional TWFE event study design. The dependent variable is the number of patent applications. Event time indicator “−4” is set to 1 for periods up to and including 4 periods prior to the event and 0 otherwise. Event time indicator “+5” is set to 1 for all periods successively following the fifth year after the event, and 0 otherwise. The period prior to the event is omitted. The bands around the point estimates are 95 percent cluster-robust confidence intervals, with LLM used as the clustering level.

TABLE A1. Connected/non-connected inventor hires and patent applications

	IV		OLS
	(1)	(2)	(3)
<i>Inventor Hire<sup>conn.</sup></i>	0.659** (0.256)	0.700** (0.274)	0.116** (0.051)
<i>Coeff. on Inventor Hire<sup>conn.</sup></i> <i>equal to col 2 (p-value)</i>			0.034
<i>Inventor Hire<sup>nonconn.</sup></i>	0.029 (0.036)	-0.266 (0.223)	0.104*** (0.029)
<i>Coeff. on Inventor Hire<sup>nonconn.</sup></i> <i>equal to col 2 (p-value)</i>			0.097
<i>Coeff. on Inventor Hire<sup>conn.</sup></i> <i>equal to Inventor Hire<sup>nonconn.</sup></i>	0.025	0.010	0.843
First Stage on <i>Inventor Hire<sup>conn.</sup></i>			
<i>Displ. Inventor<sup>conn.</sup></i>	0.048*** (0.014)	0.048*** (0.014)	
<i>Displ. Inventor<sup>nonconn.</sup></i>	0.048** (0.023)	0.004*** (0.001)	
<i>AP F-statistics</i>	11.03	14.21	
First Stage on <i>Inventor Hire<sup>nonconn.</sup></i>			
<i>Displ. Inventor<sup>conn.</sup></i>		0.006 (0.006)	
<i>Displ. Inventor<sup>nonconn.</sup></i>		0.008*** (0.002)	
<i>AP F-statistics</i>		14.18	
<i>N</i>	79,961	79,961	79,965

Note: Estimates refer to Equation (3). The dependent variable is the number of patent applications. The estimation sample includes only firms with more than five observations in the period of interest. Numbers in parentheses are standard errors clustered at the LLM level. Network size, the number of displaced workers in the same LLM  $\times$  industry  $\times$  year, firm, and time-fixed effects, and industry and LLM trends are always included. \* $p < 0.1$ , \*\*  $p < 0.05$ , and \*\*\*  $p < 0.01$ .