Tacit knowledge transfer from academia to the regional industrial cluster through Ph.D. graduates' mobility: the Stanford University case

Pr Michel Ferrary

Université de Genève – GSEM & Skema Business School

Michel.Ferrary@unige.ch

Résumé :

L'association de la mobilité professionnelle à la mobilité géographique des scientifiques universitaires jette un nouvel éclairage sur le transfert de connaissances de l'université à l'industrie et sur les contributions des universités au pôle industriel régional. La mobilité des scientifiques universitaires vers les entreprises locales nourrit l'écosystème régional. Au niveau régional, pour soutenir la croissance, un tel transfert dépend de l'alignement et de la cohérence entre les capacités d'exploration des universités et les capacités d'exploitation des entreprises. L'alignement crée un cercle vertueux d'une relation symbiotique : les scientifiques universitaires nourrissent l'industrie locale qui, en retour, en grandissant, nécessite plus de scientifiques universitaires et soutient l'université en collaborant avec des scientifiques restés dans les institutions universitaires.
Pour soutenir les propositions, la mobilité professionnelle et géographique de Stanford Ph.D. diplômés en informatique de 1966 à 2016 est analysé en mettant l'accent sur le début de l'industrie Internet en 1994/1995. Les titulaires d'un doctorat en informatique possèdent des connaissances précieuses pour contribuer à l'industrie Internet. L'analyse de leur mobilité permet de comprendre la contribution de Stanford à l'essor de cet écosystème high-tech dans la Silicon Valley.

Mots-clés : Transfert de connaissances, université-industrie, mobilité des chercheurs universitaires

Tacit knowledge transfer from academia to the regional industrial cluster through Ph.D. graduates' mobility: the Stanford University case

INTRODUCTION

Literature on industrial clusters and regional ecosystems of innovation points out the complementarity between universities and firms to support regional development (Bikard & Marx, 2020; Engel, 2015, Etzkowitz & Leydesdorff, 2000; Jacobides, Cennamo & Gawer, 2018; Feldman et al., 2023; Miller, McAdam & McAdam, 2018; Mindruta, 2013). There is a labor division in innovation between the two kinds of organizations (Arora & Gambardella, 1994). By doing basic research, universities create new knowledge. However, they are not suited for its exploitation. Universities are explorative organizations (Bikard & Marx, 2020). Academic knowledge needs to be transferred to industry to be commercially exploited through combination with industrial knowledge (in-house R&D, manufacturing, and marketing competences) (Salter & Martin, 2001; Perkmann & Walsh, 2007). In this respect, firms are exploitive organizations (Arora et al., 2018; Ferrary, 2011). Open innovation literature has emphasized the importance of University to Industry Knowledge Transfer - UIKT – to contribute to industrial cluster (Chesbrough, 2003).

Capturing and measuring UIKT is an important research topic and a major concern for policymakers that fund basic research. Conventionally, the whole process of knowledge transfer is supposed to start from tacit basic academic knowledge converted into explicit basic academic knowledge with publications before being eventually transformed into explicit applied academic knowledge with patents to finally be transferred to firms through patent licensing in order to be industrialized and commercialized. Consequently, patents usually remain the main metrics for empirical research on UIKT (Kaiser et al., 2018).

However, several scholars acknowledge that patenting captures a limited part of UIKT (Agrawal & Henderson, 2002; Arundel & Kabla, 1998; Arvanitis et al., 2008; Bercovitz & Feldman, 2006; Fleming, King, and Juda, 2007; Grimpe & Hussinger, 2013; Perkmann & Walsh, 2007). The reality is more complex as knowledge might transfer through multiple channels (Agrawal, 2001; Bercovitz & Feldmann, 2006; Hsu & al, 2015; Schartinger et al., 2002; Trippl, 2013). It is a matter of the fact that all basic research does not translate into scientific articles, that all scientific articles do not systematically lead to patents, and that all patents are not commercialized. Patents are relevant to capture explicit knowledge transfer. However, a large part of academic knowledge remains tacit and embodied in scholars. Fleming et al. (2007:951) summarize this issue *"Even though study patent collaboration networks which are based on the codified publication of patent records, much information remains tacit, private, and not communicated. This occurs because written documents can rarely capture all the richness of technology and because inventors and their firms often withhold information contained in patents for strategic reasons".*

Acknowledging that a large part of academic knowledge remains tacit, I build on scholars asserting that tacit knowledge is embodied in people (Simon, 1991; Nonaka, 1994; Grant, 1996) and that socialization is required to transfer it (Granovetter, 1985; Nonaka, 1994) to consider academic scientists' mobility as a pipe of UIKT. Tacit academic knowledge embodied in scholars is academic know-how and academic know-whom. Its transfer takes three dimensions. First, by moving to industry an academic scholar transfer his or her embodied tacit knowledge (Know-how). Second, professional mobility of academic scientists contributes to build strong ties between academic and industrial scientists working in the same firm (socialization). Third, existing social ties with his or her former academic colleagues (Know-whom) are pipes that bridge boundaries between universities and firms to support further knowledge transfer. Therefore, investigating academic scientists' mobility highlights where universities transfer their knowledge and with which organizations they create social ties to convey further knowledge transfer.

Tacit knowledge transfer requiring socialization (Nonaka, 1994) induces that geographical proximity between people matters to transfer knowledge and supports social interactions. The socialization dependency of tacit knowledge transfer explains why geographical distance affects knowledge spill-over from Academia to industry (Feldman et al., 2023; Ferrary & Granovetter, 2009) and why regional industrial cluster development may depend on professional and geographical mobility of academic scientists. Regional industrial cluster development depends on the alignment between local university specialization and local industry specialization. Professional and regional mobility of academic scientists contribute to support a regional symbiotic growth by articulating complementary of exploration and exploitation activities in a specific industrial field.

For this research, I consider professional and geographical academic scientists' mobility as a metric to capture tacit knowledge transfer in order to address the following research question: How does academic scientists' professional and geographical mobility bring a new perspective on regional industrial cluster development and complementarity between Academia and industry?

Coupling professional mobility with the geographical mobility of academic scientists sheds new light on universities' contributions to regional industrial cluster. Academic scientists' mobility to local businesses nurtures the regional ecosystem. I assume that at a regional level, to sustain growth, such transfer depends on the alignment and consistency between the explorative capabilities of universities and the exploitative capabilities of firms. Academic scientists tend to move to the regional industry when their competences are aligned with those required by local businesses. In case of mismatch, they move to other regions. Alignment creates a virtuous circle: academic scientists nurture the local industry that, in return, by growing, requires more academic scientists and supports the university by collaborating with academic scientists remained in Academia. In that way, the relationship between the kinds of organizations qualified as symbiotic (Egerton, 2015).

To support the propositions, I analyze the professional and geographical mobility of Stanford Ph.D. graduates in computer science from 1966 to 2016. PhDs in computer science own valuable knowledge to contribute to the Internet industry. I consider 1995 as a milestone in a longitudinal research. The foundation of Netscape in 1994 and its initial public offering (IPO) in 1995 are considered as the starting date for the internet industry in Silicon Valley (Joint Venture Silicon Valley, 2010). With the internet industry's boom, Ph.D. graduates in computer science were in high demand, especially in Silicon Valley, where several prominent internet companies were created. The growth of the internet industry in Silicon Valley has partly been nurtured by the mobility of Ph.D. graduates in computer science from Stanford. The founding of Yahho! In 1994 and Google in 1998 by former Stanford PhD graduates in computer science are the more striking examples. In return, this has encouraged enrollment of students in this Ph.D. program. The relationship between Stanford University and Google is a particular case that highlights how academic scientists' mobility transfers knowledge and bridges academic and industrial organizations to nurture both of them in a symbiotic way.

In the first part, I explain why academic knowledge tacitness justifies the use of academic scientists' mobility as a metric to analyze UIKT. Then I reexplore the question of the university's contribution to regional industrial cluster. In the second part, I analyze professional and geographical mobility of Stanford University's Ph.D. graduates in computer science from 1966 to 2016. The last part is dedicated to the discussion.

1. TACITNESS OF ACADEMIC KNOWLEDGE AND PIPES OF TRANSFER TO INDUSTRY

1.1. THE IRREDUCIBLE TACITNESS OF ACADEMIC KNOWLEDGE

Scholars in knowledge management converge to stress that, originally, new knowledge is tacit and created by individuals (Polanyi, 1966; Simon, 1991; Nonaka, 1994; Grant, 1996; Cowan et al., 2000). After creation, tacit knowledge may be disembodied and codified to be transferred. The conversion of tacit knowledge into explicit knowledge is called "externalization" (Nonaka, 1994). Individuals may learn explicit knowledge through "internalization" (Nonaka, 1994). The transfer of the disembodied explicit knowledge does not require social interactions between the knower and the learner. However, the capability to create new knowledge remains a tacit knowledge embodied in individuals and it requires social interactions to be transferred.

Similarly, in academia, initially, new academic knowledge is tacit and produced by individual cognitive activities based on reading, research and/or experimentation (internalization). New tacit academic knowledge is diffused through social interactions and discussions with other scientists in conferences, seminars, or informal talks (socialization). Such tacit knowledge may be desembodied and made explicit by codifying artifacts such as scientific articles, dissertations, books, conference papers, or patents (externalization). This explicit academic knowledge may easily be transferred out of the academic boundaries to industrial scientists and contribute to innovation through "combination" (Nonaka, 1994). No social interaction between academic and industrial scientists is required to transfer explicit academic knowledge. A firm may buy academic articles or patents to make them accessible to its scientists. It is a transactional process of explicit knowledge transfer that fits with a conventional understanding of UIKT (Siegel et al., 2003).

However, in Academia also, all tacit knowledge is not explicitable. When they acquire patents or publications, businesses often agree on consulting contracts with academic scientists who originated this codified knowledge in order to access to the related tacit knowledge (Azagra-Caro et al., 2017). Several reasons can explain why academic knowledge remains tacit and is not patented. First, some knowledge like scientific know-how or experience is intrinsically tacit and is not patentable (Cowan et al., 2000; Crespi & al., 2007). Academic scientists accumulate know-how such as application of information technology and data processing, report writing and presentation skills, project management skills, problem solving capability (Lee et al., 2010). They also accumulate know-whom (Defillippi and Arthur, 1994) or social capital by interacting with academic colleagues in their university and their scientific community. They know who owns specific knowledge among the members of their social network. These ties are idiosyncratic and remains tacit. Second, academic scientists are poorly incentivized to patent their knowledge and contribute to its transfer to industry (Anton & Da, 2003; Balconi & Laboranti, 2006). Academic careers depend more on publications than on patents. Moreover, the financial incentive offered by universities to patent is usually relatively poor. Third, there is a cultural limitation to patenting. Academic scientists promote information transmission because they adhere to the norms of the open information disclosure characteristic of public science (Owen-Smith & Powell, 2004), and they do not patent because they are focused on nonproprietary academic research (by contrast with for-profit organizations). Last, academic scientists informally "own" intellectual property on their tacit knowledge. Codification through patenting legally transfers intellectual property rights to the employer, i.e. the university. By avoiding to codify their knowledge, academic scientists keep their informal intellectual property and can eventually leave academia to commercialize their knowledge.

Therefore, patent licensing represents a small share of UIKT. Agrawal and Henderson (2002) point out that only 10-20% on average of the faculty in their sample from Massachusetts Institute of Technology (MIT) file a patent in any given year and that patents account for as little as 7% of the knowledge that transfers from the university to industry. Similarly, Fini et al. (2010) find that approximately two-thirds of businesses started by academics are not based on disclosed and patented inventions. Cohen, Nelson, and Walsh (2002) stress that patents and licensing are the only useful channels for technology transfer in certain industries, pharmaceutical being one of them. In other sectors, and in the majority, other channels of knowledge transfer are preferred such as publications/reports and informal information exchange, conferences, and consulting. They also point out that only about 11% of the knowledge obtained from academia by the private sector was transferred through patents.

The remaining tacitness of academic knowledge explains why patent licensing is not a major pipe of knowledge transfer. Cowan et al. (2000) even assert that the information presented (in codified form) in a patent is insufficient to allow others to actually make use of the patented

invention, and it is the correlative 'tacit knowledge' that resides with the innovator that provides the real source of private, rent-appropriating (monopoly) power.
Therefore, the remaining tacitness of academic knowledge keeps the question of UIKT open (Grimpe & Hussinger, 2013, Perkmann & Walsh, 2007). How does tacit knowledge transfer from Academia to industry? How to capture such transfer ? It is worth clarifying knowledge transfer mechanisms depending on their nature because both seem to be exclusive. Beekers & Bodas-Freitas (2008) found that the correlation coefficient between "explicit-written" and "tacit-embodied" transferred knowledge from academia is less than 0.3.

1.2. ACADEMIC SCIENTISTS' MOBILITY AS TACIT UIKT AND CREATION OF PIPES OF UIKT

Several scholars suggest that academic scientists' professional mobility is one of the most important forms of knowledge transfer to industry (Meyer-Krahmer & Schmoch, 1998; Balconi & Laboranti, 2006; Bekkers & Bodas-Freitas, 2008). Schartinger et al. (2002) show that personnel mobility is intensively used, especially in chemistry, biotechnology, engineering, and information technology to support UIKT. Mangematin & Nesta (1999) stress that the transfer of knowledge from Academia is based on labor mobility.

1.2.1. Professional mobility to industry as transfer of tacit academic know-how

Tacit knowledge being embodied in individuals means two things when it comes to its transfer. First, a firm can acquire such knowledge by recruiting academic scientist or by fostering social interactions between its industrial scientists and academic scientists. Building on the second item of Simon's assertion (1991) that « *an organization learns in only two ways: (a) by the learning of its members, or (b) by ingesting new members who have knowledge the organization did not previously have,"* one assumes that industry learns from academia by hiring academic scientists. Zellner (2003) points out the economic benefits of scientists' migration to the commercial sector to contribute to innovation. Several case studies and qualitative research suggest that recruitment is a way for a firm to acquire new knowledge from a university (Cohen and Levinthal, 1990; Jain, 2016; Kaiser et al., 2018; Singh & Agrawal, 2011; Tzabbar, 2009). When academic scientists leave academia to move to industry to become industrial scientists in large firms, research centers, or start-ups, they bring with them their tacit academic knowledge (Feldman et al.; 2006). One important function of academic research is the provision of trained research personnel, who go on to work in applied activities and take with them not just the knowledge resulting from their research, but also skills and, methods, that will help them tackle the technological problems they later face (Lee, Miozzo & Laredo, 2010; Bozeman et al., 2015). Hiring researchers with university experience provide the firm with science-based and problem-solving capabilities (Kaiser et al., 2018). Zellner (2003) points out that what is valued by scientists in the commercial sector of the innovation system is the acquired capability to formulate, structure, and solve a diverse range of problems, informed by their broad scientific background. By moving to industry, academic scientists bring their scientific know-how.

Professional mobility to industry also strongly socializes academic scientists with their new industrial colleagues. Tacit knowledge requires relational coordination and face-to-face interactions between people to be transferred (Nonaka, 1994; Schartinger et al., 2002). Stressing that socialization matters to transfer tacit knowledge means that social ties should exist or should be built beforehand knowledge transfer. Economic sociology (Granovetter, 1985) brings a complementary perspective on socialization and UIKT. When moving to a business, an academic scientist gets embedded in a new professional network and socialize with new colleagues. Such socialization contributes to transfer tacit knowledge. Belonging to the same organization contributes to create strong ties between former academic scientists and industrial scientists. Strong ties are large pipes of knowledge transfer (Rosenkopf & Almeida, 2003; Martin et al., 2006; Senker, 1995; Varga, 2000).

Proposition 1: Academic scientists' mobility transfers embodied tacit know-how from academia to industry

1.2.2. Professional mobility transfers know-whom to bridge Academia and industry to transfer knowledge

Scholars mention that interpersonal networks contribute to inter-organizational collaboration between university and firms and support knowledge transfer (Bekkers & Bodas-Freitas; 2008). However, few research investigate the origin of such inter-organizational networks. I assert that academic scientists mobility contributes to bridge university and industry. The more a university provides academic scientists to a organization, the more both are embedded in a connected social network. The flow of people underpines the flow of knowledge between organizations by embedding academia and industry in similar social networks. The relevance of interorganizational and social networks for innovation-related processes is rooted in the nature of knowledge creation as a socially embedded process (Perkmann and Walsh, 2007).

Grossetti (2008) found that mobility within local job markets explains most of the local relations between organizations. People maintain links in the organizations they have passed through (university, companies), and these links can be mobilized in their professional activity. Socialization is characterized by stickiness. When an academic scientist moves to a business, he keeps ties with his former academic colleagues and such ties might support more tacit knowledge transfer between the two organizations.

In other words, an academic scientist moving to a firm keeps his social network (or his social capital) in academia and bridges his new employer with the former. These ties bridging universities and firms are pipes that support further knowledge transfer by fostering collaborative projects.

Past mobility may eventually foster further mobility that will support more embodied tacit knowledge transfer. Fleming et al. (2007) point out that the connectedness of Stanford University and IBM Almaden Valley labs was due to numerous recruitments of Ph.D. graduates by IBM that bridged the two organizations. They mention that university professors and their former students maintain close ties at conferences and continue to visit each other long after their inventive collaboration.

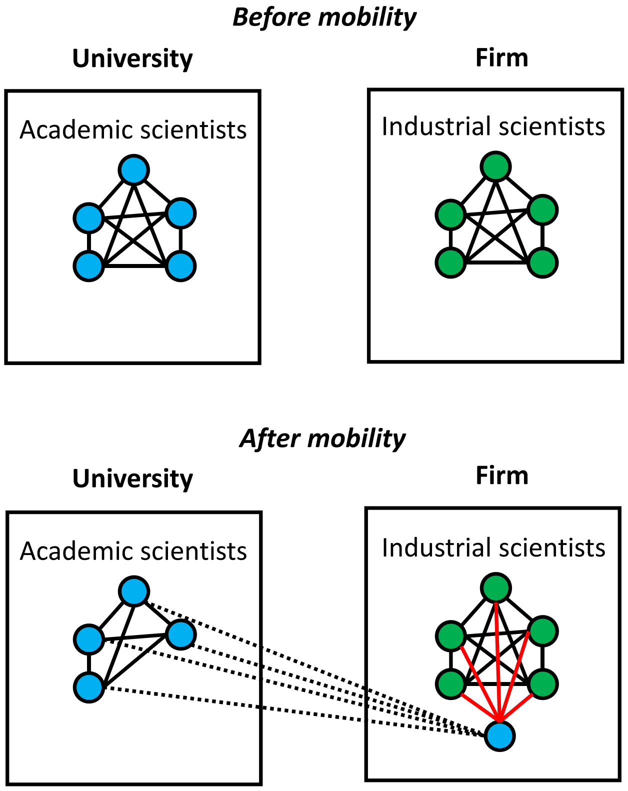
The know-whom transfer allows by academic scientists' mobility contributes to interorganizational socialization that support further interorganizational transfer of know-how. It also fosters further interorganizational academic scientists mobility toward industry and, therefore, transfer more tacit academic know-how. Therefore, tracking academic scientists' mobility also contributes to identifying with which organizations universities build bridges that are pipes for further tacit knowledge transfer.

Proposition 2: Academic scientists' mobility bridges universities with businesses by transferring tacit know-whom that creates pipes for further tacit knowledge transfer

To summarize, investigating academic scientists' mobility highlights two dimensions: to which organizations university transfers its tacit knowledge embodied in its academic scientists and with which organizations it bridges through social ties to support further knowledge transfer (Figure 1).

Figure 1

Tacit knowledge embodied in individual and social ties



Legend:
_____ *Strong ties*
.... *Weak ties*

2. Academic scientists' geographical and professional mobility and regional innovation ecosystem

Focusing on academic scientists' mobility instead of other instruments (for example patents) may shed a new light on a critical question in UIKT: how does university contribute or not to regional innovation ecosystem? Professional mobility of academic scientists being a pipe of UIKT induces a related question: what about the geographical destination of this mobility? Do academic scientists move to local industry and contribute to the regional ecosystem by transferring knowledge or do they go away? Is regional scientific specialization aligned with regional industrial specialization to nurture economic growth by articulating local academic explorative capabilities with local organizational exploitive capabilities through a symbiotic relationship?

Research on industrial clusters (Saxenian, 1994), ecosystem of innovation (Ferrary & Granovetter, 2009), open innovation (Perkmann & Walsh, 2007), and regional and national industrial systems (Feldman et al., 2006) emphasize the importance of transferring knowledge from academia to regional industry to nurture local innovation ecosystem. Therefore, analyzing academic scientists' geographical mobility contributes to evaluating whether knowledge produced by local universities is transferred or not to local businesses. Moreover, the local mobility of academic scientists connects the university with local organizations and contributes to inter-organizational knowledge transfer.

Geographical proximity matters when it comes to UIKT and socialization between individuals (Bikard & Marx, 2020; Feldman et al., 2023). Geographical mobility matters to create and maintain social ties between university and industry (Ferrary and Granovetter, 2009).

Regional studies point out that academic knowledge spill-over to the industry depends on the geographical proximity between the university and the businesses. Scholars identify proximities effects (Jaffe et al., 1993; Singh & Marx, 2013; Grossetti, 2008) and geographical proximity induced by industrial clusters enhances exchanges between research institutions and firms. Academic knowledge absorption by firm depends on the recruitment of academic scientists that are able to absorb the knowledge (Cohen & Levinthal, 1990). Therefore, the regional absorption of local universities knowledge partly depends on the geographical mobility of its academic scientists. Local mobility of academic scientists affects the two dimensions of tacit knowledge transfer: transferring tacit know-how and building bridging ties between Academia and industry by transferring know-whom.

The geographical proximity condition for creating and maintaining social ties explain why large firms implement research centers close to universities. Such proximity helps recruitments of local academic scientists and collaboration with local universities. For example, Amazon, IBM, Xerox, and Microsoft have implemented research centers in Silicon Valley far from their headquarters to connect with Stanford University. Similarly, European pharmaceutical companies like Roche, Novartis, and Sanofi have research centers around Cambridge to connect with biotech and medical research centers at Harvard and MIT.

Proposition 3: local mobility of academic scientists nurtures a dynamics regional growth of the innovation ecosystem when academic and industrial specializations are aligned

Access to talent has been proven important for developing high-tech clusters (Feldman et al., 2006). Costs for search and recruitment are reduced when large talent pools are available, and a cluster tends to be more attractive for talents if there is a likelihood of obtaining work. Knowledge transfer from university is heavily impacted by the concentration of high technology employment in a given area (Varga, 2000). Academic scientists, being highly educated, are considered more mobile than other workers, and they rather flow to places where their field of work is booming (Florida,1999). There is interdependency between scientific specialization at the local university and the regional industrial specialization to nurture a virtuous circle of economic growth. The explorative capabilities of universities need to be aligned with the exploitive capabilities of local industry to foster the local mobility of academic scientists and contribute to the local diffusion of knowledge. Such alignment fosters local mobility of academic scientists which favor local collaboration between universities and businesses. In case of misalignment, academic scientists may prefer to quit the region.

Alignment supports a virtuous circle of reinforcing the demand and supply of academic scientists that may nurture local growth in a symbiotic relationship. University training academic scientists (supply) that migrate locally to contribute to industrial growth. Such growth increases local demand for academic scientists and universities, local firms and individuals will support more research programs in the field. Alignment between academic specialization and regional industrial specialization underpins a symbiotic relationship between university and regional businesses. Conversely, in case of misalignment, when the local industry does not provide positions for local trained academic scientists, the latter move away to find jobs and, therefore, do not contribute to the local economy. Thus, investigating the geographical mobility of academic scientists contributes to finding whether academic knowledge is locally transferred and whether universities build bridges with local industry to contribute to regional development or not.

Proposition 4: local mobility of academic scientists depends on the alignment between the academic specialization and the industrial specialization

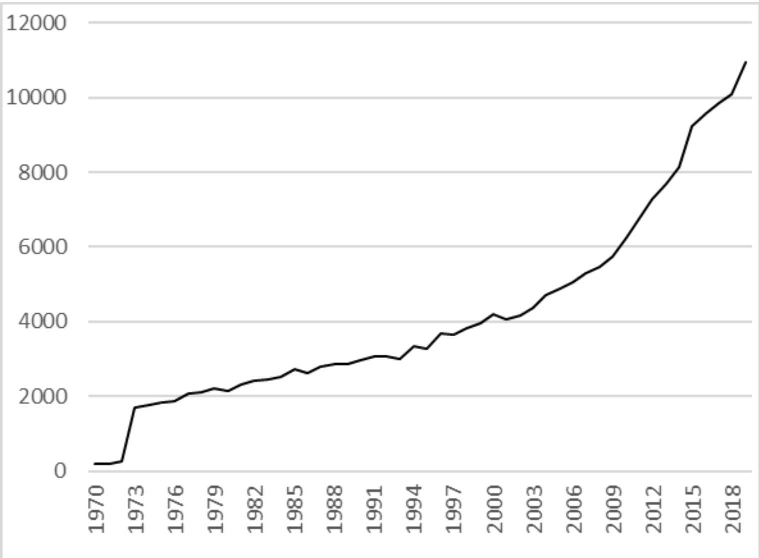
2. CASE STUDY: PH.D. GRADUATES IN COMPUTER SCIENCE FROM STANFORD UNIVERSITY AND SILICON VALLEY INTERNET ECOSYSTEM

2.1. METHODOLOGY

2.1.1. Stanford University as valuable case study for UIKT

For several reasons, Stanford University is an interesting case to investigate the question of knowledge transfer from Academia to industry and its impact on the regional ecosystem. First, Stanford University is frequently identified as one of the top universities in the world for the quality of its scientific research. The primary condition to explore whether a university transfers knowledge to the industry is to know if this organization creates high-quality academic knowledge that could be transferred. Hicks (1995) asserts that publications signal a university's research quality, including the existence of tacit knowledge and unpublishable resources. Scientific publications result from a process of externalization of basic research and the number of scientific articles is a proxy for the quantity of academic research. The number of scientific articles published by Stanford scientists is massive and keep growing over time (Figure 2).

Figure 1 – Stanford academic publications (web of science)



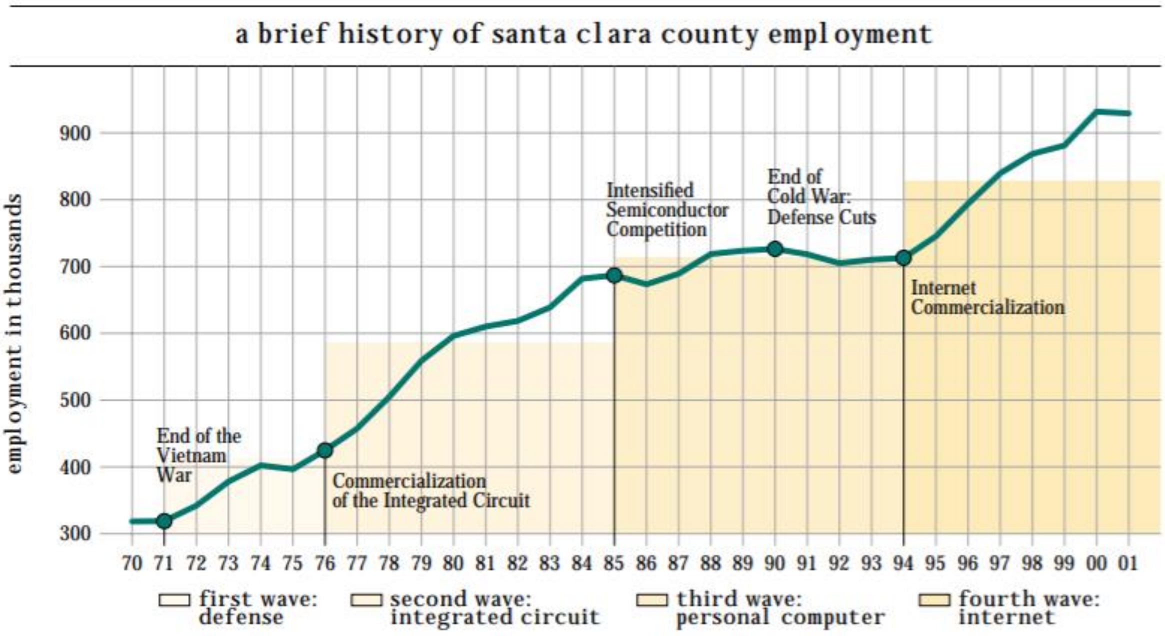
Second, Stanford University is well identified as a key component of the Silicon Valley high-tech cluster (Bercovitz & Feldman, 2006; Ferrary & Granovetter, 2009). According to Stanford records, about 39,900 companies have been founded by Stanford alumni[1]. This has led to the creation of 5.4 million jobs and annual revenues of $2.7 trillion. Out of those 39,900 companies, 18,000 are headquartered in the Silicon Valley area, employing more than 3 million people.

Third, Silicon Valley is identified as the cradle of the Internet industry (Joint Venture Silicon Valley, 2010). Internet technology was invented in the 1970s with the Arpanet network but remained of military and academic use until the end of the 1980s. The diffusion of the technology in the private sector and the linking of commercial networks and enterprises in the early 1990s triggered the growth of the internet industry (Figure 2). The foundation of Netscape in 1994 by James Clark, Ph.D. graduate in computer science and former professor at

[1] Stanford Facts, 2019

Stanford, and its Initial Public Offering in 1995 are considered as the starting point of the internet industry. Several prominent internet companies were created in this region (Yahoo! in 1994, eBay in 1995, Google in 1998, Facebook in 2004, Saleforce in 1999, Netflix in 1997; Paypal in 1998; Uber in 2009, Twitter in 2006 to name few of them) underpinning a significant economic growth in the region (Heaton, Siegel and Teece, 2019).

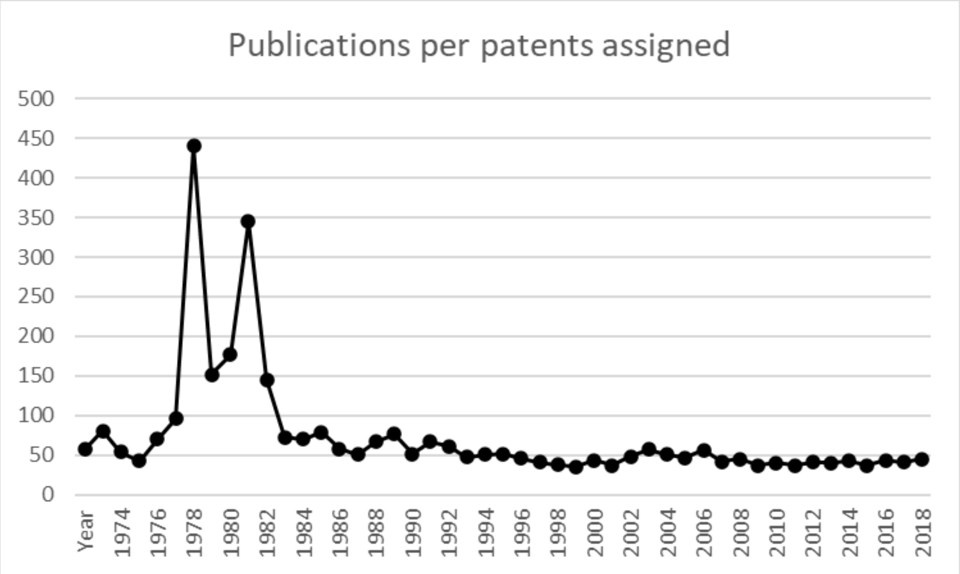
Figure 2 – Technological cycles and economic growth in Silicon Valley



Sources: Economy.com, Collaborative Economics

Fourth, Stanford University also illustrates the limits of using patents and patent licensing to evaluate UIKT. Considering scientific publications as explicit basic academic knowledge, invention disclosures as explicit applied academic knowledge, and patent licensing as transferred academic knowledge. There is a growing gap between academic knowledge produced and academic knowledge transferred. In 2001, according to the Web of Science, Stanford University published 6474 scientific articles and 14971 in 2018 (+131%). In comparison, the number of new technology disclosures increased from 277 in 2001 to 560 in 2018 (+102%), but the number of licenses concluded increased only from 137 in 2001 to 150 in 2018 (+9,5%). Excepted at the beginning of the 80s, the Stanford ability to convert publications (Basic academic knowledge) into patents (explicit applied knowledge) remains stable over time (Figure 3).

Figure 3



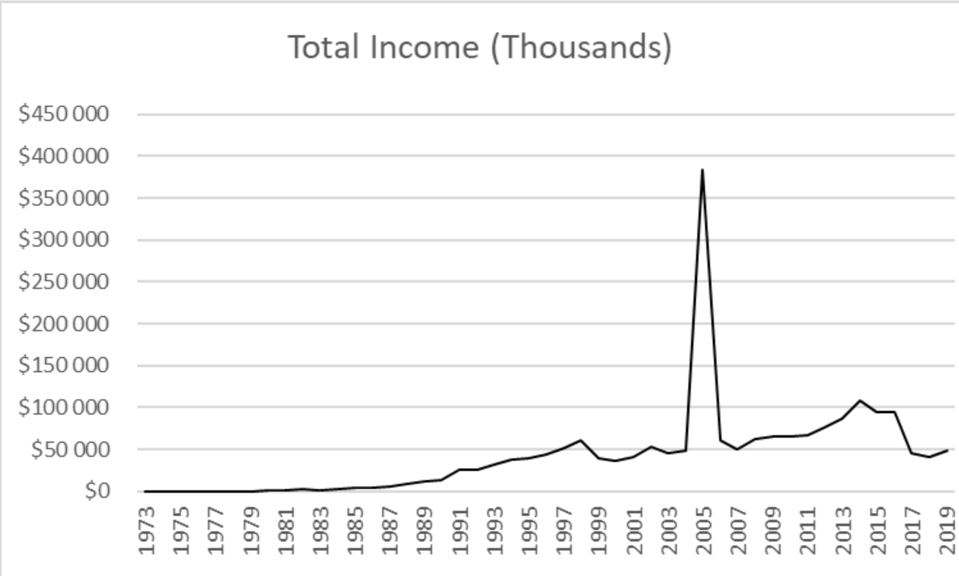
Revenues generated by the Stanford OTL lead to the same conclusion. Since 1970, Stanford's OTL has received $1.91 billion in licensing income, but only 98 out of approximately 12,000 inventions have generated more than $1 million (Life of a Stanford Invention, 2018). Through its Office of Technology Licensing (OTL), Stanford received $40.96 million in gross royalty revenue in 2017-2018 (Stanford Innovation & Inventions, 2019), which represents a low proportion of Stanford's total operating revenues of $11.3 billion in 2018. The amount of money received has remained stable over the years (Figure 4). The conversion of academic knowledge into industrial knowledge through licensing agreements keeps decreasing. In 2001, the ratio of publications/licensing agreements was 47/1 in 2001 and 100/1 in 2018. The ratio of OTL gross revenues per publication was $6364 in 2001 and only $2736 in 2018.

Google is presented as a striking successful case of technology transfer through a licensing agreement that generated incredible revenues for the university. However, Googleremains an exception that is visible with the peak on the OTL revenues graph (Figure 4). Google was founded by Larry Page and Sergey Brin. They were Ph.D. students in computer science at Stanford University. In 1996, they participate to a research project to design an algorithm ranking websites based on their relevance. The idea to rank web pages was the theme for the Page dissertation. They got funding from the National Science Foundation. In 1998, they published an academic article [2] and, the same year, with the support of the Stanford OTL, as an inventor, Larry Page filed a patent "method for node ranking in a linked database". The patent was assigned to Stanford University and the Stanford OTL sets a licensing agreement

[2] *Brin S. & Page L. (1998). "The anatomy of a large-scale hypertextual Web search engine" Computer Networks and ISDN Systems. 30 (1–7): 107–117*

for 1.8 million Google shares. The company was incorporated in September 1998. After Google's IPO in 2004, Stanford sold its 1.8 million shares for a value of $335 million, resulting in the biggest one-year gain ever registered by an OTL (Krieger, 2010).

Figure 4 -Stanford OTL revenues



The licensing agreement is just one dimension of the knowledge transfer from Stanford University to Google. The fact that the two Ph.D. graduates left Academia to create the start-up was a major tacit knowledge transfer from Stanford university to industry. Moreover, the fact that Google settled in Palo Alto and then in Mountain View, two cities very close to Stanford University has helped the two founders to keep social ties with their former colleagues and professors to initiate collaboration and further recruitment and knowledge transfer.

Google remains an exception to a successful transfer of codified knowledge through patent licensing. The reality is more like Yahoo!. In 1994, David Filo and Jerry Yang, Ph.D. students at Stanford, founded Yahoo! when they discovered the possibility of creating a directory of websites. Their directory became increasingly popular on campus and later grew to become the leader of search engines (Mccullough, 2015). The two founders built their website during their free time, that was officially not part of their assignments as Stanford scholars, and therefore did not need any license from the university, although much of the resources at Stanford had been used by (Lebret, 2012). Focusing only on patent to capture UIKT means that formally no knowledge has transferred from Stanford to Yahoo!. Many other companies that contributed to the growth of the internet industry have been created by former Stanford scientists based on knowledge accumulated at Stanford but without any patent or license belonging to the university, such as VMware[3], Sun Microsystems[4], or Cisco Systems[5].

Stanford University illustrates what has been identified by several scholars: patent licensing captures a limited part of UIKT. This justifies exploring other metrics such as academic scientists' mobility to explore tacit knowledge transfer and the Stanford's contribution to the internet regional high-tech cluster (Agrawal & Henderson, 2002; Eesley & Miller, 2012).

2.1.2. PhD graduates' mobility as a vector of tacit knowledge transfer from university to industry

Several scholars suggest that academic scientists' mobility could be a valuable instrument for evaluating UIKT (Crespi et al. (2007; Perkmann & Walsh,2007). Few articles empirically explore academic scientists' mobility and they mainly focus on professors' mobility (Zucker et al., 2002). However, professors, especially tenured professors, have limited incentive to move to industry to large firms or to create start-ups (Thursby &Thursby,2002; Bercovitz & Feldmann, 2010). Therefore, focusing on professors' mobility limits the understanding of knowledge transfer through academic scientists' mobility and justify to focus on other populations.

Conversely, Ph.D. graduates are academic scientists who are more likely to move to industry. After graduation, they can choose between an academic or an industrial career and transfer their knowledge to industry. However, only few studies highlight the knowledge operated by the recruitment of Ph.D. graduates in the private sector (Mangematin, 2000). Nevertheless, out of the 23 channels of knowledge transfer from university to industry identified by Bekkers & Bodas-Freitas (2008), "University graduates as employees (Ph.D. level)" is ranked by university R&D performers as the third more important channel of knowledge transfer (after "scientific publications" and "informal contact").

Ph.D. graduates are considered to be professional researchers. Buenstorf & Heinisch (2020) point out " *New PhDs are highly specialized experts who worked for several years on advancing the state of the art in their field of research. While PhDs are required to reveal their findings in their doctoral dissertation, large parts of the knowledge they gained in their dissertation work remains tacit (e.g., failed experiments/trials) and thus is not accessible*

[3] Edouard Bugnion was a PhD candidate in computer science before co-founding VMware in 1998
4 Andy Bechtolsheim received a PhD in electrical engineering from Stanford before co-founding Sun Microsystems in 1982

[5] Leonard Bosck was Master graduate in computer science from Stanford and in charge of the computer science department support before leaving the university to co-found Cisco Systems in 1984

through the published results. Firms' access to this tacit knowledge may nonetheless be crucial to turning dissertation results into innovative products and processes. Labor mobility of new PhDs therefore provides a fruitful channel of knowledge transfer from universities to the private sector". Hiring Ph.D. graduates allows firms to acquire academic knowledge, skills, and techniques that often are tacit (Pavitt, 1991; Salter & Martin, 2001; Santoro & Gopalakrishnan, 2000). Therefore, it makes sense to focus on Ph.D. graduates as academic scientists and investigate their mobility as a pipe of UIKT.

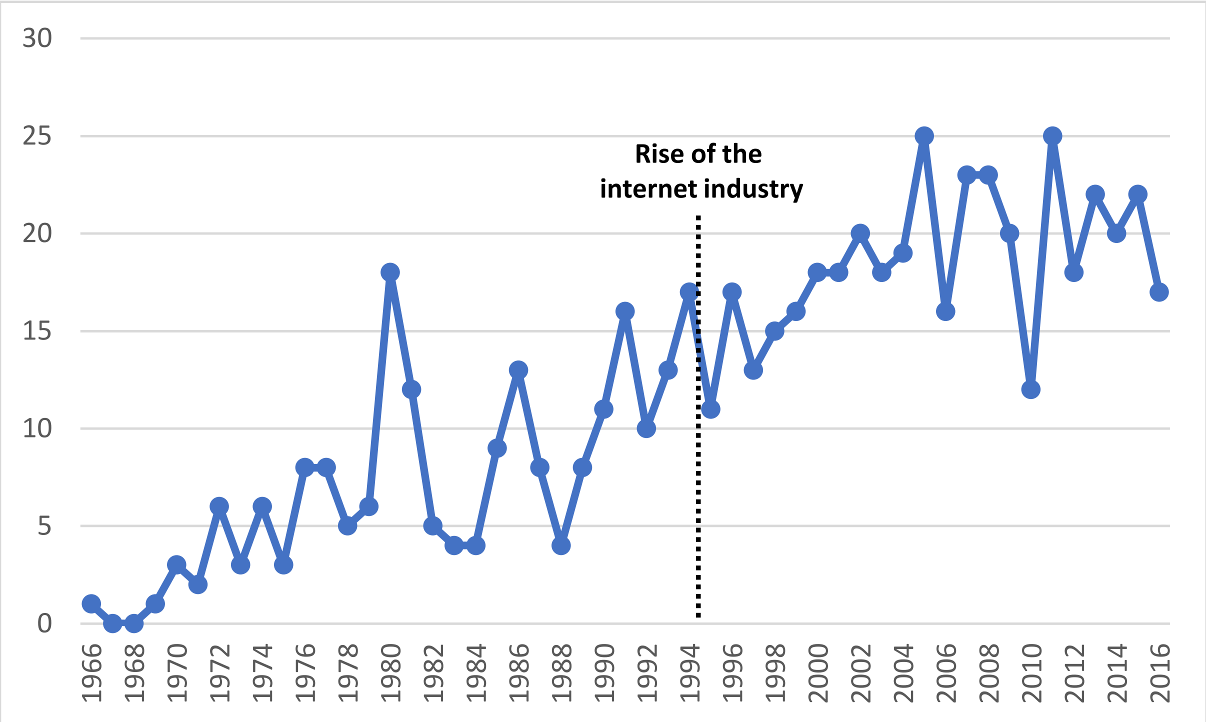
Using academic scientists' mobility to capture UIKT in Silicon Valley has already been mobilized by Fleming et al. (2007). They point out that from 1986 to 1990, Ph.D. graduates' mobility from Stanford University to IBM Labs in Silicon Valley nurtured the flow of knowledge between these organizations and fostered innovation. Our research differs from Fleming et al. (2007) by investigating Ph.D. graduates in computer science from Stanford University on a longer period (from 1966 to 2016) and, with a particular attention on 1994-1995; period that marks the rise of the internet industry in Silicon Valley. Knowledge of Ph.D. graduates in computer science was in high demand in the internet industry. From 1985 to 1994, before the internet industry, semiconductors were the dominant industry in the region and required less knowledge in computer science. Therefore, it makes sense to investigate how the rise of the internet industry in Silicon Valley has affected the professional and geographical mobility of Ph.D. graduates in computer science from Stanford University. From a dynamic perspective, one can explore how the alignment between scientific specialization (explorative capabilities) at Stanford University and industrial specialization (exploitive capabilities) of regional enterprises has been built through Ph.D. mobility and local ties between academia and industry. Moreover, investigating academic scientists' mobility to evaluate knowledge transfer makes sense because software in the internet industry is poorly patentable and limits the use of patent licensing to capture knowledge transfer.

Our propositions are consistent if, before 1995, more Ph.D. graduates in computer science remain in academia and/or move out of California because the internet industry may not still exist and that other industries in the region require less knowledge related to computer science. Our propositions are also consistent if, after 1995, the number of Ph.D. graduates in computer science from Stanford increased to fulfill the needs of the industry, also if more Ph.D. graduates moved to the industry (large firms, private research centers or start-ups) and more of them remained in California where the Silicon Valley- the internet industry birthplace- is located. Thus, investigating in which organizations Ph.D. graduates move to contribute to identifying where they transfer their knowledge and which organizations they bridge with Stanford University.

The initial data set was obtained from Stanford University. It was the list of all its Ph.D. graduates in computer science since the program started in 1965 until 2016. Data on the positions held by PhDs just after graduation were collected using LinkedIn. Out of the 902 Ph.D. graduates, data was available for 619 of them. Four potential professional destinations are identified: academia, large firm, private research center and start-up and, two geographical destinations : in California or out of California.

2.2. Professional and geographical mobility of Stanford Ph.D. graduates in computer science

Figure 5: Graduates from the Stanford PhD program in Computer Science



Since its inception in 1965, the Stanford Computer Science program has graduated more and more students over the years (Figure 5). The total numbers have steadily increased since its first year with few fluctuations. After the mid-1990s, the numbers are characterized by a steep rise (excepted for the 2009-2010 economic crisis). The Ph.D. program has increased its enrollments concomitantly to the growth of the internet industry in Silicon Valley.

2.2.1. Professional mobility: in or out of Academia

Over the period 1966 - 2016, a vast majority (75.4%) of Ph.D. graduates in computer science from Stanford University moved to industry and transfer it their knowledge; only 24.6% remain in Academia (Table 1). That means the large part of tacit academic knowledge embodied in PhD graduates transfers to industry.

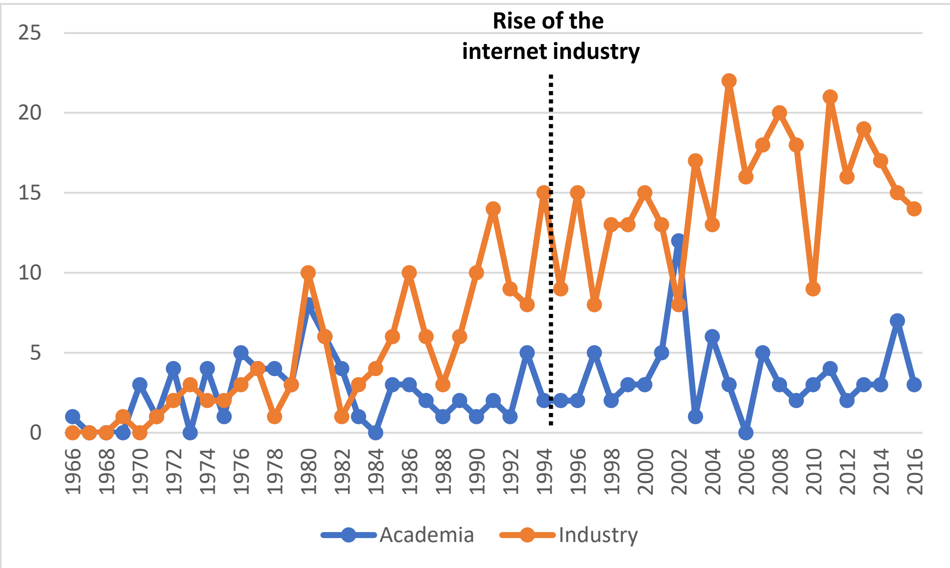
Large groups are the leading destination for Ph.D. graduates moving to industry (65.5% out of the 467 moving to the industry goes to large groups).

Table 1 – Professional mobility from 1966 to 2016

Professional mobility	University	Large Group	Research Center	Start-up	Total
PhD graduates	152	305	36	126	619
Percentage	24,6%	49,3%	5,8%	20,4%	100,0%

However, the distribution evolved over time. The number of Ph.D. graduates remaining in academia is stable over time. After the mid-1990s, the number of Ph.D. graduates moving to industry keeps growing, meaning the increase in Ph.D. graduates' enrollment was mainly to train academic scientists who end up in the industry (Figure 7). The growth of Ph.D. graduates correlates with the growth of the internet industry in Silicon Valley, suggesting that both nurture each other[6]. The drop in 2002 is due to the internet burst in 2000 that reduced the demand of PhD by the industry.

Figure 7 – Number of PhD graduates in and out Academia



[6] The two exceptions are the two economic crises that decreased the demand for academic scientists in the labor market: the internet burst (2001-2002) and the subprime crisis (2009): During these two crises, mobility to industry decreased and more Ph.D. graduates remained in academia.

Considering the 1995 turning point emphasizes the increasing propensity of Ph.D. graduates to move to industry when the internet industry started to grow. From 1966 to 1994, 34,6% of Ph.D. graduates remain in Academia and 65,4% move to the industry (Table 5) From 1995 to 2016, only 19,6% remain in Academia and 80,4% move to industry (Table 6).

Table 5 – Professional mobility from 1966 to 1994

1966 - 1994	University	Large Group	Research Center	Start-up	Total
PhD graduates	71	95	21	18	205
Percentage	34,6%	46,3%	10,2%	8,8%	100,0%

Table 6 – Professional mobility from 1995 to 2016

1995 - 2017	University	Large Group	Research Center	Start-up	Total
PhD graduates	81	213	14	106	414
Percentage	19,6%	51,4%	3,4%	25,6%	100,0%

When it comes to professional mobility to industry, 1995 is also a turning point. Before 1995, only 8.8% of Ph.D. graduates move to start-ups (Table 5). After 1995, the percentage is 3 times larger to reach 25.6% (Table 6). Considering numbers indicates that 5.8 times more Ph.D. graduates move to start-ups (18 vs. 106) between the two periods.

2.2.2. Geographical mobility : In or out Silicon Valley

From 1966 to 2016, the majority of Ph.D. graduates (57.4%) remained in California (Table 7).

Table 7 – Geographical mobility from 1966 to 2016

1966-2016	Number	Percentage
California	355	57,4%
Out of California	264	42,6%
Total	619	100%

However, the geographical mobility has changed over time. Before 1995, more Ph.D. graduates (127 out of 205) left California (62%) than remained (38%) (Table 8). Conversely, after 1995, more Ph.D. graduates (277 out 414) remained in California (66.9%) than left (33.1%) (Table 9).

The rise of the internet industry in Silicon Valley seems to retain more Ph.D. graduates in computer science in California, and Stanford University provides 3.5 times more Ph.D. to the region from 1995 to 2016 than from 1966 to 1994 (78 before and 277 after).

Figure 8 – Geographical mobility: in and out California

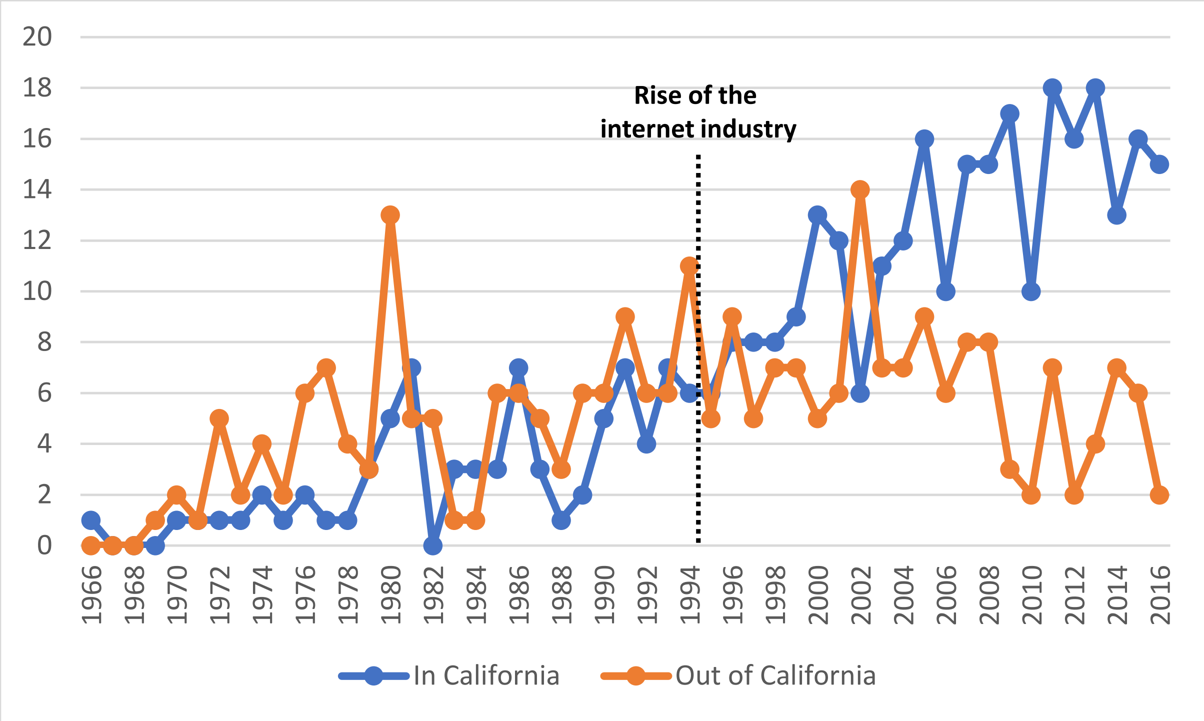


Table 8 - Geographical mobility from 1966 to 1994

1966-1994	Number	Percentage
California	78	38,0%
Out of California	127	62,0%
Total	205	100%

Table 9 - Geographical mobility from 1995 to 2016

1995-2016	Number	Percentage
California	277	66,9%
Out of California	137	33,1%
Total	414	100%

2.2.3. Mixing professional and geographical mobility: the turning point of 1995

Mixing the two dimensions: professional mobility (university, large group, research center, or start-up) and geographical mobility (in or out of Silicon Valley) emphasizes the 1995 turning point. Even before 1994, Ph.D. graduates staying in California tended to move more out of academia (only 23.1% remain in academia) than those leaving the state (41.7%) (Table 7). This propensity increased a lot after 1995. Only 8.7% of those staying in California after 1995 remain in academia, and 91.3% move to industry. After 1995, the propensity of Ph.D. graduates leaving California to remain in academia stays stable (41.6%) (Table 8). The rise of the internet industry in Silicon Valley retains more and more Ph.D. graduates in the local industry (Figure 9).

Figure 9 – Geographical and professional mobility: the rise of Silicon Valley

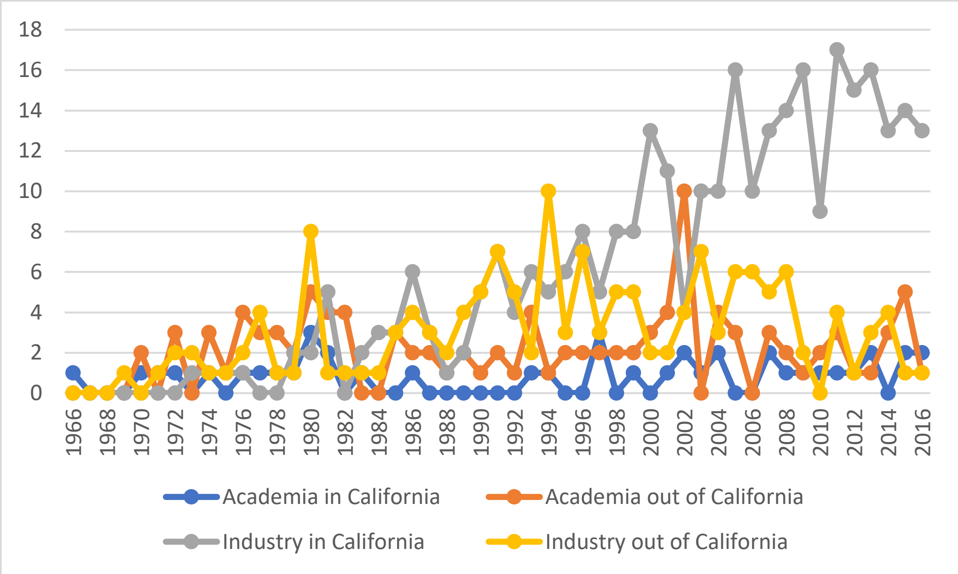


Table 10 – Professional mobility in and out of California: 1966-1994

1966 - 1994	University	Large Group	Research Center	Start-up	Total
California	23,1%	39,7%	19,2%	17,9%	100,0%
Out of California	41,7%	50,4%	4,7%	3,1%	100,0%

Table 11 – Professional mobility in and out of California. 1995-2016

1995 - 2017	University	Large Group	Research Center	Start-up	Total
California	8,7%	54,2%	2,9%	34,3%	100,0%
Out of California	41,6%	46,0%	4,4%	8,0%	100,0%

Another major change appears when one focuses on Ph.D. graduates remaining in California and moving to industry. After 1995, more Ph.D. graduates moved to start-ups (23.3% before 1994 and 37.5% after), and fewer moved to research centers (Table 12 and 13). Numbers highlight even more the tendency. Before 1995, 14 Ph.D. graduates remaining in California moved to start-ups. After 1995, 95 of them moved to start-ups, 6.8 times more than before 1995.

Table 12 – Mobility to the industry in and out of California: 1966-1994

1966 - 1994	Large Group	Research Center	Start-up	Total
California	51,7%	25,0%	23,3%	100,0%
Out of California	86,5%	8,1%	5,4%	100,0%

Table 13– Mobility to industry in and out of California: 1995-2016

1995 - 2017	Large Group	Research Center	Start-up	Total
California	59,3%	3,2%	37,5%	100,0%
Out of California	78,8%	7,5%	13,8%	100,0%

The rise of the internet industry in Silicon Valley changed the dynamics of the professional and geographical mobility of Ph.D. graduates. First, more graduates remained in California and many of them moved to start-ups. 89.6% of Ph.D. graduates who moved to start-ups remained in California. This is consistent with Feldman and Francis's (2002) findings that entrepreneurs who start companies do not relocate but instead stay close to the source of their perceived competitive advantage, which is typically the referent organization where the founder was previously employed.

2.3. Ph.D. graduates' mobility bridges Stanford University with different organizations

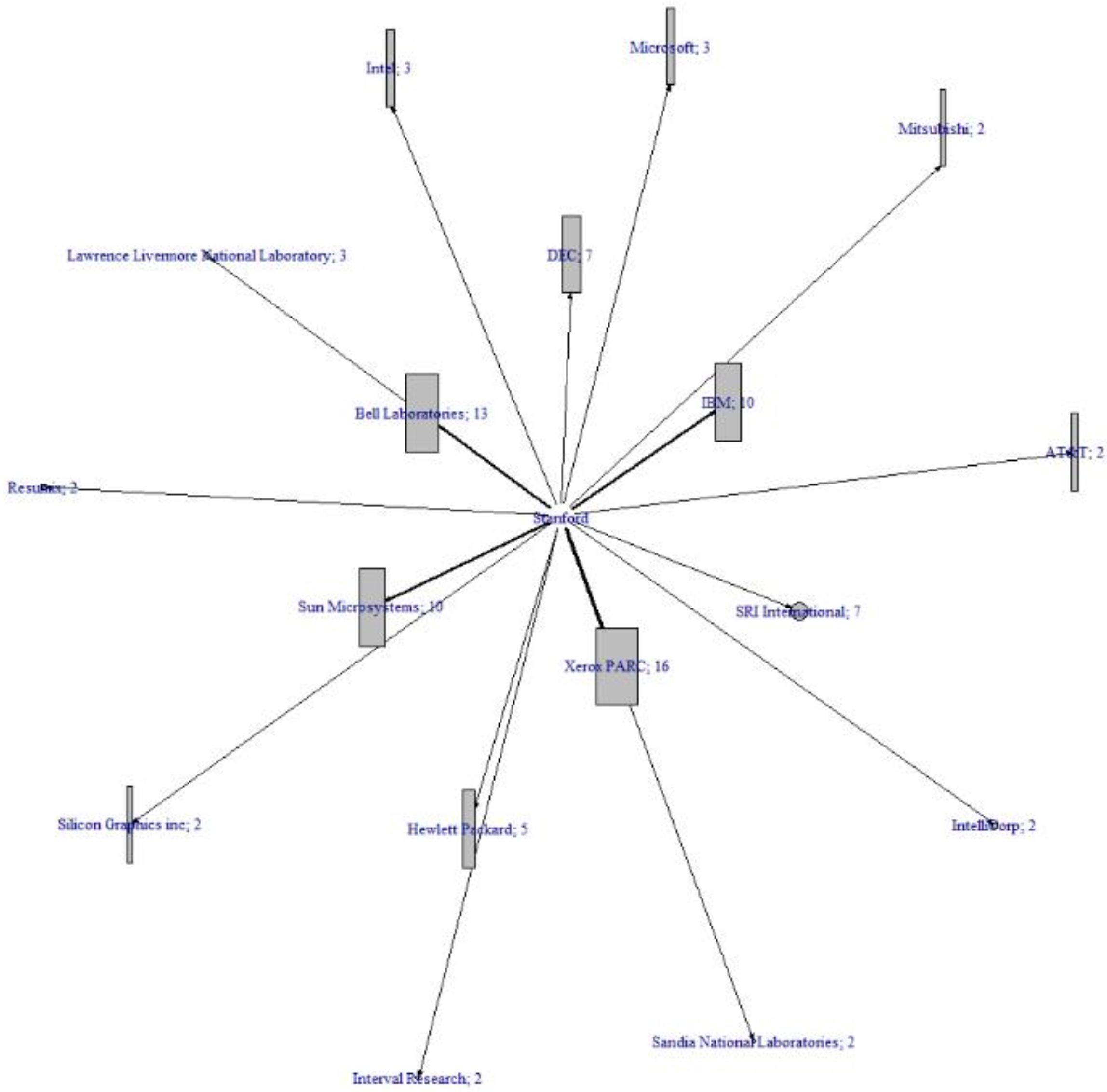
2.3.1. Before 1995

From 1966 to 1994, 134 Ph.D. graduates move to the industry to 59 different organizations: large firms, research centers, or start-ups (Table 14). They did it more out of California than in. Only 17 organizations have recruited two or more Ph.D. graduates (Graph 1). Out of the five major recruiters: Xerox/Parc (16), Bell Labs (13), IBM (10), Sun Microsystems (10), and DEC (7), only one was created in Silicon Valley and is headquartered in the region (Sun Microsystems). The other four, even if they have research centers in California, are headquartered out of the state, where strategic decisions are taken by the top management of the firm. Moreover, Sun Microsystems was created in 1982 by former Stanford students (one PhD in electrical engineering and two MBA graduates).

Table 14 – Professional and geographical mobility in industry from 1966 to 1994

1966 - 1994	Large Group	Research Center	Start-up	Total
California	31	15	14	60
Out of California	64	6	4	74
Total	95	21	18	134

Graph 1 – Ph.D. graduates' mobility from Stanford University to industry: 1966-1994



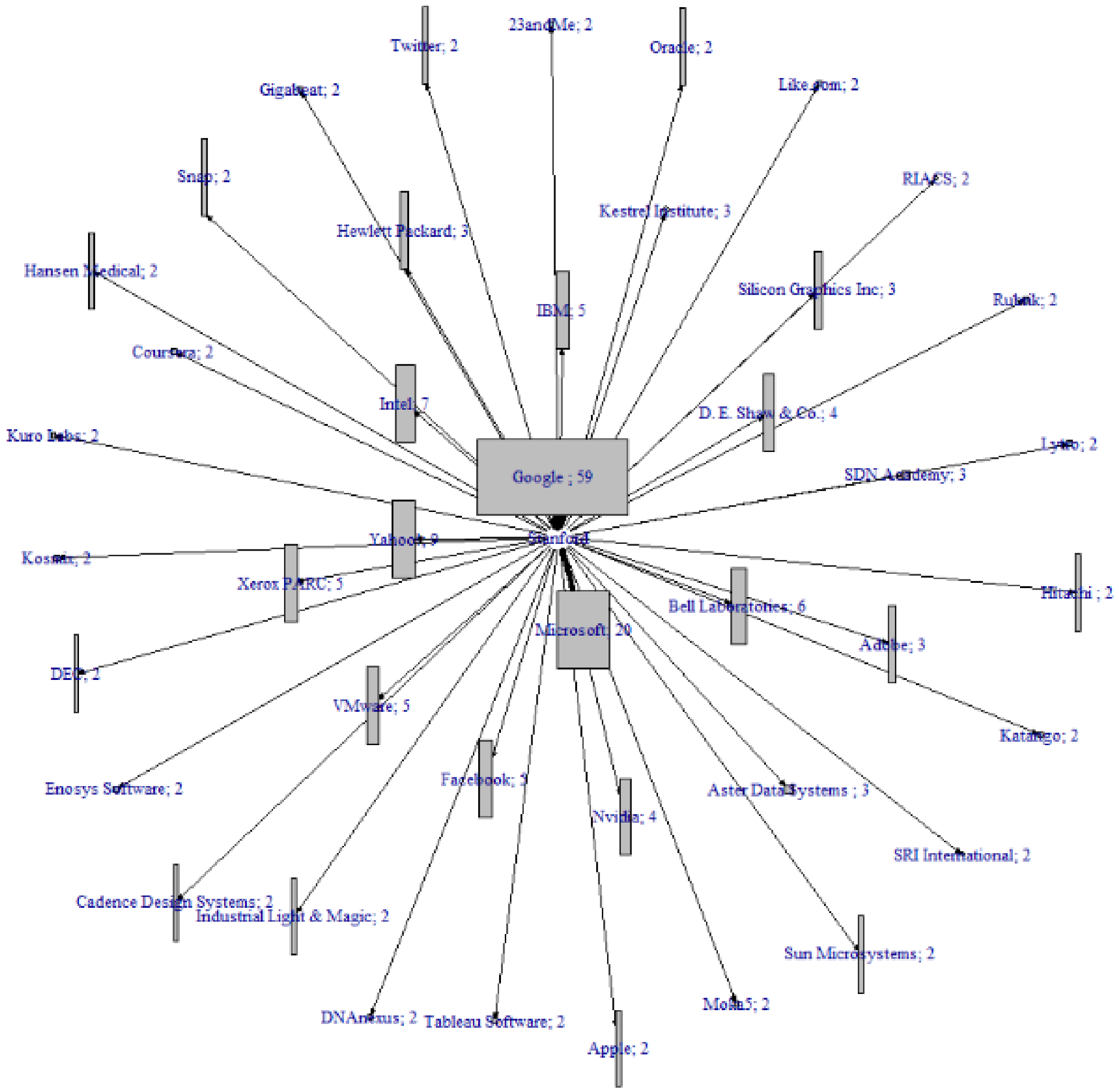
2.3.2. After 1995

The picture is different over the period 1995-2016. First, by training more PhDs in computer science, Stanford University has more potential vectors to transfer its knowledge to the industry. Considering the propensity to move to industry increased after 1995 means that Stanford University is connected with more businesses, especially in California. From 1995 to 2016, 333 Ph.D. graduates moved to industry, more in California than out (Table 15). They moved to 162 different organizations, and several of them are headquartered in Silicon Valley (Google, Yahoo!, Intel, Netflix, Facebook, WMware, Nvidia, Adobe, etc.) (Graph 2). The alignment between academic and industrial specialization in the region favors local mobility. Moreover, to take advantage of the knowledge produced by Stanford, several high-tech companies out of the region created entities there to be able to recruit PhD graduates and nurture cooperation with the university. Microsoft, Xerox and IBM being three of them.

Table 15 – Professional and geographical mobility in industry from 1995 to 2016

1995 - 2017	Large Group	Research Center	Start-up	Total
California	150	8	95	253
Out of California	63	6	11	80
Total	213	14	106	333

Graph 2 – Ph.D. graduates' mobility from Stanford University to industry: 1995-2016



Google is a particular case. Since its inception in 1998 and 2016, the firm has recruited 59 Ph.D. graduates in computer science from Stanford university, representing 19.6% of Ph.D. graduates moving to the industry and 25.2% of those moving to the industry in California. In 1998, Google was a start-up founded by two Stanford Ph.D. students in computer science, Larry Page and Sergey Brin. The start-up growth was nurtured by a flow of Ph.D. graduates that brought their knowledge and helped bridge the two organizations. Google's headquarters in Mountain View is located less than 10 kilometers from Stanford University. Several Google projects started in cooperation with Stanford University. For example, to develop its project on autonomous car Google first built on a collaboration with Stanford academic scientists and then recruited academic scientists from this university. Sebastian Thrun, professor of computer science at Stanford University and director of the Stanford Artificial Intelligence Laboratory, is the co-inventor of the Street View mapping service. In 2005, with a team of Stanford students and faculty members, they designed the Stanley robot car, winning the second Grand Challenge of the Defense Advanced Research Projects Agency, a $2 million Pentagon prize for driving autonomously over 132 miles in the desert. In 2011, he was recruited by Google to run the self-driving car initiative. Before this recruitment, Google collaborated with SAIL. The collaboration was initiated and made possible by the numerous former Stanford Ph.D. graduates working at Google (without mentioning the two founders). The geographical proximity between the two organizations also contributes to Ph.D. mobility and collaborations.

The Stanford University – Google case illustrates that UIKT cannot be reduced to patent and patent licensing. Except for the 1998 license, Stanford OTL did not license any more patents to Google and only six patents have been co-assigned to Stanford and Google. Conversely, investigating Ph.D. mobility highlights that a massive quantity of knowledge encapsulated in Stanford academic scientists transferred to Silicon Valley in general and more specifically, to Google. This mobility also transferred social capital to build bridges between the two organizations to transfer more knowledge through social ties and inter-organizational collaborations. Ph.D. mobility strongly embedded Stanford University and Google. The local alignment between the Stanford scientific specialization in computer science with the regional industrial specialization nurtured the internet industry growth in general and, more particularly, Google's growth. In return, the local industry has supported the Stanford specialization by developing collaborative projects and interacting frequently. Google being a paramount case of a symbiotic relationship created between the two organizations through the mobility of Ph.D. graduates. However, several local firms support or have supported research activities at Stanford. A visible clue of this support is the number of buildings on the campus to welcome ore Stanford scholars that were funded by high-tech companies, some of them created by Stanford alumni. Just to mention some of them: Hewlett and Packard, founders of Hewlett-Packard and Stanford alumni, have funded two buildings; James Clark, founded of Netscape and former Stanford professor has funded a building, Jen-Hsun Huang, co-founder of NVIDIA and alumna, has funded a building; Robert Moore, co-founder of Intel has funded a building; Jerry Yang, co-founder of Yahoo! And alumna also funded a building, Bill Gates and Paul Allen, co-founders of Microsoft, have also funded two buildings and their firm have several research centers in the region. Local companies like Fairchild, Cypress and Varian, some founded by alumni have also funded a building on the campus (without mentioning facilities founded by alumni in others fields such medicine, biology, environment or business). On the top of funding facilities and provide material resources, executives and engineers from these local companies teach classes, give seminars and participate to research projects with Stanford scientists.

The Stanford Computer Forum is a cooperative venture of the Computer Science Department and Electrical Engineering Departments, and 60+ companies located in Silicon Valley, the rest of the U.S., Asia, and Europe. The Forum provides a mechanism for developing interaction with industrial researchers and their academic counterparts, promoting the exchange of the most advanced technological ideas in fields of computer science and electrical engineering. The Forum offers industry the opportunity to become familiar with the professional abilities and interests of Stanford students through its active recruiting program.

The computer science department was founded in 1965 by George Forsythe, and, in 2022, counts 72faculty, 79 post-doctoral students and 464 PhD students.

3. DISCUSSION

This research aimed to build on well-established limitations of using patents and patent licensing to capture knowledge transfer from academia to industry. Starting from the assertion that a significant part of scientific knowledge produced by academic scientists remains tacit and encapsulated in their heads, one proposes to use the professional mobility of academic scientists as an instrument to measure knowledge transfer from academia to industry. One also considers the bridging effect of professional mobility that spans structural holes by creating social ties between organizations. An academic scientist moving to another organization brings in knowledge but keeps his social ties with his former colleagues and bridges the two organizations. Therefore, investigating academic scientists' mobility contributes to capture tacit knowledge transfer from academia to industry. It also contributes to explore embedding mechanisms that bridge universities and businesses.

Another purpose of this research is to investigate the question of knowledge transfer from university to the industry at a regional level to explore how a university contribute to its surrounding ecosystem by transferring knowledge to local organizations and by connecting with local businesses through the mobility of its academic scientists.

To address these questions, one analyzes Stanford University and the mobility of its Ph.D. graduates in computer science. Stanford University is a huge producer of scientific knowledge measured by academic articles. However, it appears that Stanford University patents few inventions and licenses even fewer of them. Using patent metrics could lead to the wrong conclusion that Stanford University does not transfer knowledge to the industry. Using Ph.D. graduates' mobility sheds a different light on the question. One considers that Ph.D. graduates encapsulate tacit academic knowledge created in academia, therefore the fact that 75.4% of Ph.D. graduates in computer science from 1966 to 2016 moved to industry shows that Stanford University transferred to industry a tremendous part of the scientific knowledge it produced. Moreover, considering that the number of Ph.Ds increases over time and that an increasing portion of them move to industry show that the transfer of knowledge from Stanford to industry increases over time.

Second, the question of the aligning the scientific specialization and explorative capabilities between local universities and the industrial specialization and exploitive capabilities of the local businesses is critical to contribute to regional development. Open innovation depends on a networked ecosystem, and inter-organizational social networks between academia and industry play an essential role in driving innovation processes (Perkmann & Walsh, 2007). Moreover, the two kinds of organizations may contribute to such alignment by supporting each other. The Stanford University-Silicon Valley internet industry illustrates the positive impact of such alignment.

Geographical proximity matters in creating and maintaining social ties to channel knowledge. Therefore, one can expect that Ph.D. graduates remaining in California tend to keep ties with their alma alter and channel more knowledge from university than those leaving California.

Flemming et al. (2007) point out the importance of the geographical proximity between Stanford University and IBM Almaden Valley Labs to develop cooperative mobility.

Focusing on Ph.D. mobility gives a different picture of UIKT and contributes to overcoming the limitations of research using patents. For example, Fleming et al. (2007) used patents to evaluate collaboration and UIKT from Stanford to IBM Californian research center. They faced a paradox: Ph.D. graduates moved to IBM, but patenting did not show any evidence of UIKT and could lead to conclude that UIKT failed *("The lack of result for employee mobility (as proxied by the assignees per inventor variable) is surprising, as personnel movement across firms should arguably increase creativity"* (Fleming et al. (2007:949)). An alternative explanation is that knowledge has really been transferred but remained tacit and was shared with other scientists, and was not patented, because not patentable or kept secret.

REFERENCES

Arundel, A., & Kabla, I. (1998). What percentage of innovations are patented? Empirical estimates for European firms. *Research Policy*, *27*(2), 127-141.
Agrawal, A. K. (2001). University-to-industry knowledge transfer: Literature review and unanswered questions. *International Journal of Management Reviews*, *3*(4), 285–302.
Agrawal, A., & Henderson, R. (2002). Putting Patents in Context: Exploring Knowledge Transfer from MIT. *Management Science*, *48*(1), 44–60.
Ahmadpoor, M., & Jones, B. F. (2017). The dual frontier: Patented inventions and prior scientific advance. *Science*, *357*(6351), 583-587.
Alcacer, J., & Gittelman, M. (2006). Patent citations as a measure of knowledge flows: The influence of examiner citations. *The Review of Economics and Statistics*, *88*(4), 774-779.
Ankrah, S., & Al-Tabbaa, O. (2015). Universities-industry collaboration: A systematic review. *Scandinavian Journal of Management*, *31*(3), 387–408.
Anton, J. J., & Yao, D. A. (2003). Patents, invalidity, and the strategic transmission of enabling information. *Journal of Economics & Management Strategy*, *12*(2), 151-178.
Arora, A., & Gambardella, A. (1994). Evaluating technological information and utilizing it: Scientific knowledge, technological capability, and external linkages in biotechnology. *Journal of Economic Behavior & Organization*, *24*(1), 91-114.
Arvanitis, S., Kubli, U., & Woerter, M. (2008). University-industry knowledge and technology transfer in Switzerland: What university scientists think about co-operation with private enterprises. *Research Policy*, *37*(10), 1865-1883.
Azagra-Caro, J. M., Barberá-Tomás, D., Edwards-Schachter, M., & Tur, E. M. (2017). Dynamic interactions between university-industry knowledge transfer channels: A case study of the most highly cited academic patent. *Research Policy*, *46*(2), 463-474.
Balconi, M., & Laboranti, A. (2006). University–industry interactions in applied research: The case of microelectronics. *Research Policy*, *35*(10), 1616-1630.
Bekkers, R., & Bodas Freitas, I. M. (2008). Analysing knowledge transfer channels between universities and industry: To what degree do sectors also matter? *Research Policy*, *37*(10), 1837–1853.
Belenzon, S., & Schankerman, M. (2013). Spreading the word: Geography, policy, and knowledge spillovers. *Review of Economics and Statistics*, *95*(3), 884-903.
Bercovitz, J., & Feldman, M. (2006). Entrepreneurial universities and technology transfer: A conceptual framework for understanding knowledge-based economic development. *The Journal of Technology Transfer*, *31*(1), 175-188.
Bikard, M. and M. Marx (2020), 'Bridging academia and industry: how geographic hubs connect university science and corporate technology,' Management Science, **66**(8), 3425–3443.
Bozeman, B., Rimes, H., & Youtie, J. (2015). The evolving state-of-the-art in technology transfer research: Revisiting the contingent effectiveness model. *Research Policy*, *44*(1), 34–49
Buenstorf, G., & Heinisch, D. P. (2020). When do firms get ideas from hiring PhDs?. *Research Policy*, *49*(3), 103913.
Caldera, A., & Debande, O. (2010). Performance of Spanish universities in technology transfer: An empirical analysis. *Research policy*, *39*(9), 1160-1173.
Chesbrough, H. W. (2003). *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business Press.
Clayton, P., Donegan, M., Feldman, M., Forbes, A., Lowe, N., & Polly, A. (2019). Local Prior Employment and Ecosystem Dynamics. *ILR Review*, 0019793919836756.
Cockburn, I. M., & Henderson, R. M. (1998). Absorptive capacity, coauthoring behavior, and

the organization of research in drug discovery. *The Journal of Industrial Economics*, *46*(2), 157-182.
Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2002). Links and Impacts: The Influence of Public Research on Industrial R&D. *Management Science*, *48*(1), 1–23.
Cowan, R., & Foray, D. (1998). The economics of knowledge and the diffusion of knowledge. *Industrial and Corporate Change*, *16*(3), 1–11.
Cowan, R., David, P. A., & Foray, D. (2000). The explicit economics of knowledge codification and tacitness. *Industrial and corporate change*, *9*(2), 211-253.
Crespi, G. A., Geuna, A., & Nesta, L. (2007). The mobility of university inventors in Europe. *The Journal of Technology Transfer*, *32*(3), 195-215.
DeFillippi, R. J., & Arthur, M. B. (1994). The boundaryless career: A competency‐based perspective. *Journal of organizational behavior*, *15*(4), 307-324.
Egerton, Frank N. "History of ecological sciences, part 52: Symbiosis studies." *The Bulletin of the Ecological Society of America* 96.1 (2015): 80-139.
Eesley, C. E., & Miller, W. F. (2012). Impact: Stanford University's Economic Impact via Innovation and Entrepreneurship. *Ssrn*, (October), 1–104.
Engel, J. S. (2015). *Global Clusters of Innovation: 57*(2), 36–65.
Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. *Research policy*, *29*(2), 109-123.
Feldman, M., & Desrochers, P. (2003). Research universities and local economic development: Lessons from the history of the Johns Hopkins University. *Industry and Innovation*, *10*(1), 5-24.
Feldman, M. P., & Francis, J. (2002). The entrepreneurial spark: Individual agents and the formation of innovative clusters. In *Complexity and industrial clusters* (pp. 195-212). Physica-Verlag HD.
Feldman, M., Gertler, M., & Wolfe, D. (2006). University technology transfer and national systems of innovation: Introduction to the special issue of industry and innovation. *Industry and Innovation*, *13*(4), 359-370.
Feldman, M., DiBiaggio L. and Tan T. (2023), The temporal value of local scientific expertise, Industrial and Corporate Change, 00, 1-26
Ferrary, M. (2011). Specialized organizations and ambidextrous clusters in the open innovation paradigm. *European management journal*, *29*(3), 181-192.
Ferrary, M., & Granovetter, M. (2009). The role of venture capital firms in Silicon Valley's complex innovation network. *Economy and Society*, *38*(2), 326–359.
Fini, R., Lacetera, N., & Shane, S. (2010). Inside or outside the IP system? Business creation in academia. *Research Policy*, *39*(8), 1060-1069.
Fleming, L., King III, C., & Juda, A. I. (2007). Small worlds and regional innovation. *Organization Science*, *18*(6), 938-954.
Fleming, L., Greene, H., Li, G., Marx, M., & Yao, D. (2019). Government-funded research increasingly fuels innovation. *Science*, *364*(6446), 1139-1141.
Florida, R. (1999). The role of the university: leveraging talent, not technology. *Issues in science and technology*, *15*(4), 67-73.
Grant, R. M. (1996). Toward a knowledge‐based theory of the firm. *Strategic management journal*, *17*(S2), 109-122.
Grimpe, C., & Hussinger, K. (2013). Formal and Informal Knowledge and Technology Transfer from Academia to Industry: Complementarity Effects and Innovation Performance. *Industry and Innovation*, Vol. 20, pp. 683–700.
Grossetti, M. (2008). Proximities and embedding effects. *European Planning Studies*, *16*(5),

629-642.
Heaton, S., Siegel, D. S., & Teece, D. J. (2019). Universities and innovation ecosystems: a dynamic capabilities perspective. *Industrial and Corporate Change*, *28*(4), 921-939.
Hicks, D. (1995). Published papers, tacit competencies and corporate management of the public/private character of knowledge. *Industrial and corporate change*, *4*(2), 401-424.
Jacobides, M. G., Cennamo, C., & Gawer, A. (2018). Towards a theory of ecosystems. *Strategic Management Journal*, *39*(8), 2255–2276.
Jaffe, A. B., Fogarty, M. S., & Banks, B. A. (1998). Evidence from patents and patent citations on the impact of NASA and other federal labs on commercial innovation. *The Journal of Industrial Economics*, *46*(2), 183-205.
Jaffe, A. B., & Trajtenberg, M. (2002). Flows of knowledge from universities and federal laboratories: Modeling the flow of patent citations over time and across institutional and geographic boundaries. *Proceedings of the National Academy of Sciences*, *93*(23), 12671–12677.
Kaiser, U., Kongsted, H. C., Laursen, K., & Ejsing, A. K. (2018). Experience matters: The role of academic scientist mobility for industrial innovation. *Strategic Management Journal*, *39*(7), 1935-1958.
Kaplan, A. (1964). The conduct of inquiry. Scranton. *Pa: Chandler*.
Lee, P. (2012). Transcending the tacit dimension: Patents, relationships, and organizational integration in technology transfer. *Calif. L. Rev.*, *100*, 1503.
Li, D., Azoulay, P., & Sampat, B. N. (2017). The applied value of public investments in biomedical research. *Science*, *356*(6333), 78-81.
Mangematin, V. (2000). PhD job market: professional trajectories and incentives during the PhD. *Research policy*, *29*(6), 741-756.
March, J. G. (1991). Exploration and exploitation in organizational learning. *Organization science*, *2*(1), 71-87.
Miller, K., McAdam, R., & McAdam, M. (2018). A systematic literature review of university technology transfer from a quadruple helix perspective: toward a research agenda. *R and D Management*, *48*(1), 7–24.
Mindruta, D. (2013). Value creation in university-firm research collaborations: A matching approach. *Strategic management journal*, *34*(6), 644-665.
Mowery, D. C., & Rosenberg, N. (1989). New developments in US technology policy: implications for competitiveness and international trade policy. *California Management Review*, *32*(1), 107-124.
Mowery, D. C., Sampat, B. N., & Ziedonis, A. A. (2002). Learning to patent: Institutional experience, learning, and the characteristics of US university patents after the Bayh-Dole Act, 1981-1992. *Management Science*, *48*(1), 73-89.
Nonaka, I. (1994). A Dynamic Theory of Organizational Knowledge Creation. *Organization Science*, *5*(1), 14–37.
Owen-Smith, J., & Powell, W. W. (2004). Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. *Organization science*, *15*(1), 5-21.
Peri, G. (2005). Effect on Innovation. *Knowledge Creation Diffusion Utilization*, *87*(May), 308–322.
Perkmann, M., & Walsh, K. (2007). University-industry relationships and open innovation: Towards a research agenda. *International Journal of Management Reviews*, *9*(4), 259–280.
Powers, J. B. (2003). Commercializing academic research: Resource effects on performance of university technology transfer. *The Journal of Higher Education*, *74*(1), 26-50.
Rothaermel, F. T., Agung, S. D., & Jiang, L. (2007). University entrepreneurship: a taxonomy

of the literature. *Industrial and corporate change*, *16*(4), 691-791.
Santoro, M. D., & Gopalakrishnan, S. (2000). The institutionalization of knowledge transfer activities within industry–university collaborative ventures. *Journal of engineering and technology management*, *17*(3-4), 299-319.
Senker, J. (1995). Tacit Knowledge and Models of Innovation abstract from Industrial and Corporate Change. *Industrial and Corporate Change*, *4*(2), 425–447.
Simon, H. A. (1991). Bounded rationality and organizational learning. *Organization science*, *2*(1), 125-134.Singh, J., & Agrawal, A. (2011). Recruiting for ideas: How firms exploit the prior inventions of new hires. *Management Science*, *57*(1), 129-150.
Thursby, J. G., & Thursby, M. C. (2002). Who is selling the ivory tower? Sources of growth in university licensing. *Management science*, *48*(1), 90-104.
Tzabbar, D. (2009). When does scientist recruitment affect technological repositioning?. *Academy of Management Journal*, *52*(5), 873-896.
Varga, A. (2000). Local academic knowledge transfers and the concentration of economic activity. *Journal of Regional Science*, *40*(2), 289–309.
Zellner, C. (2003). The economic effects of basic research: evidence for embodied knowledge transfer via scientists' migration. *Research Policy*, *32*(10), 1881-1895.
Zucker, L. G., Darby, M. R., & Armstrong, J. (1998). Geographically localized knowledge: spillovers or markets?. *Economic Inquiry*, *36*(1), 65-86.
Zucker, L. G., Darby, M. R., & Torero, M. (2002). Labor mobility from academe to commerce. *Journal of Labor Economics*, *20*(3), 629-660.