High-tech clusters, technology spillovers, and trade secret laws*

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Abstract

We analyze firms' incentives to cluster in an industrial district to benefit from reciprocal technology spillovers. A simple model of cumulative innovation is presented where technology spillovers arise endogenously through labor mobility. It is shown that firms' incentives to cluster are the strongest when the following three conditions are met: 1) technological progress is rapid; 2) competition in the product market is relatively soft; 3) the probability of a single firm to develop an innovation is neither very high nor very low. We show that some trade secret protection is always beneficial for firms' profits and stimulates clustering. Excessive protection may impede technology spillovers and reduce firms' incentives to cluster.

JEL Codes: *J3, K2, L1, O32, O34.*

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1 Introduction

During the 80s and the 90s Silicon Valley has been the prototypical example of a successful local industrial district. In the mid 90s it was home to twenty percent of the world's largest technology companies (*Businessweek*, 25.08.1997) and the mean income was 50 percent higher than the national figure (Audretsch, 1998). The recipe of its success has been studied extensively and several attempts have been promoted to replicate the industrial structure of Silicon Valley elsewhere in the world.

The clustering of many technology companies in a circumscribed geographical area generates several important effects (see, e.g., Marshall, 1920). First, the local market for inputs and services expands: on the one hand, this allows providers of inputs to achieve a higher degree of specialization and lower their prices; on the other hand, technology companies can deepen their own capabilities by relying on external sources for the supply of skills, technologies, and other resources.[1] Second, the concentration of firms attracts a 'deep' pool of workers. In turn, this implies that firms and workers are better matched and are less likely to be restricted in their labor demand and supply, respectively.

Finally, there is a technology spillover effect, which is the focus of our paper.[2] Technological knowledge and information, more in general, are extremely difficult to keep confined within the boundary of the firm due to their ethereal nature. The empirical evidence shows that firms' productivity increases thanks to spillovers but the beneficial effects of spillovers decay with geographic distance (Alemeida and Kogut, 1999; Jaffe et al., 1993; Acs et al., 1994). This provides an argument for spillover driven clustering. In other words, firms may want to cluster to enjoy technology spillovers from each other.[3] Such spillovers may be the result of voluntary exchanges of information, informal talks among employees, mobility of workers, or even industrial espionage.

To many, the flow of technological information across the industry has been one of the main reasons for the success of Silicon Valley. However, this argument, after a second thought, appears at least incomplete. When technological knowledge is widespread at the level of the industry, an important source of competitive advantage is leveled out - firms must compete on equal footing. Especially when product market competition is intense,

[1] "*By focusing on what they did best and purchasing the reminder from specialist suppliers, they created a network system that spread the costs of developing new technologies, reduced product-development times, fostered reciprocal innovation.*" (Saxenian, 1994). Following Krugman (1991), this effect has been studied extensively in the recent literature.

[2] Needless to say that clustering might have other effects. Some of them, such as congestion, might be undesirable.

[3] Audretsch and Feldman (1996) find evidence in this direction showing that technology intensive industries tend to cluster more than other industries after controlling for geographic concentration of production.

firms might try to locate in distant areas in order to minimize technology spillovers and preserve their competitive advantage. Ultimately, the presence of technology spillovers might turn out to be a reason against industrial clustering.

However, as Saxenian (1994) has nicely documented, technology companies cluster in Silicon Valley, engineers and technical workers change jobs repeatedly contributing to the creation of technology spillovers, and nevertheless firms compete vigorously in the product market. She reports that the annual turnover rate among highly-skilled personnel in Silicon Valley was approximately 20-25% and argues that such movement of workers between employers (and start-ups) is the result of a business culture that supports job hopping. Refining this argument, some legal scholars have stressed that trade secret protection is weak in California, and argued that this might explain the high labor turnover (Hyde, 1998; Gilson, 1999).[4] However, both explanations of the high mobility of personnel seem to forget that firms have monetary instruments to keep their employees - they might simply pay a higher wage in order to avoid turnover and constrain the outward knowledge flow.

In this paper we build a simple model that offers an economic rationale to the empirical evidence discussed above. An entrepreneur (a firm) needs a researcher (a worker) to run his R&D department. An important ingredient of our model is that knowledge and innovation are cumulative. The R&D activity gives rise to knowledge, which is valuable both for directly commercializing a product (first generation) and for being the basis for a new and better version of the product (second generation). We follow Pakes and Nitzan (1983) and endogenize technology spillovers through labor mobility.[5] After having successfully developed the first generation product, the worker can move to a rival firm enabling it to freely use the knowledge. The movement of the worker contributes to make the knowledge widespread at the industry level thereby rising the likelihood that the second generation product will be developed. We explicitly consider the competition for the services of the worker, and technology spillovers arise only if the rival firm is willing to offer a higher wage to the worker than the current employer.

Contrary to what is typically found in the literature,[6] we show that labor mobility and technology spillovers can also occur when product market competition is particularly tough. This result crucially depends on the cumulative nature of the innovation. We also show that the parameter space under which labor mobility occurs expands when the value

[4] A trade secret is any valuable piece of information that is not commonly known in the industry and that the firm makes an effort to protect. Trade secret laws protect a firm's trade secrets from misappropriation by, e.g., former employees or rival firms. See also discussion in section 5.

[5] See also Fosfuri et al. (2001), Rønde (2001), and Gersbach and Schmutzler (2002).

[6] See, for example, Pakes and Nitzan (1983) and Fosfuri et al. (2001).

of the second generation product is large relative to the first.

We then move a step backwards in the game tree and allow firms to choose locations. Each firm can either decide to locate in a separate region or to 'cluster' in the same area as the rival. In our model, technology spillovers are the only reason for firms to cluster. Put differently, technology spillovers are a necessary condition for firms to cluster. However, technology spillovers are not a sufficient condition, because workers earn a higher expected wage when firms locate together. In equilibrium, firms cluster only if the expected benefits from technology spillovers outweigh the additional wage bill.

As argued above, technology spillovers generate two opposing effects: On the one hand, technology spillovers increase the probability that the more valuable, second generation product is developed. This is the effect usually stressed in the more informal discussions of Silicon Valley. On the other hand, firms are more likely to end up with similar products and, therefore, to compete more vigorously in the product market. We identify three conditions that increase the benefits from technology spillovers and firms' incentive to cluster. First, product market competition is soft. Second, the probability of a single firm developing the second generation product is neither very small nor very large. Third, the value of the second generation product is high relative to the first.

Finally, we use our framework to analyze how the degree of trade secret protection affects both the decision to cluster and the intensity of labor mobility. We show that trade secret protection, except in some extreme cases, is beneficial for firms' profits, stimulates clustering, and is not an impediment to workers' mobility.

We now turn to the related literature. Mai and Peng (1985) use a modified Hotelling framework to study localized spillovers and industrial clustering. They assume that firms enjoy more spillovers when locating closer to each other. However, competition gets at the same time tougher, so firms never cluster completely. We consider a simpler, discrete choice of location in our model, but endogenize the source of spillovers, which is left as a 'black-box' in Mai and Peng (1985).

There are two recent papers that study the functioning of industrial clusters when spillovers arise through labor mobility, but focus on issues complementary to the ones analyzed in this paper. Cooper (2001) looks at firms' and workers' investment in R&D and human capital, respectively: an aspect that we treat only in a rudimentary way. However, he abstracts from the strategic interaction between the labor and the product markets, which plays a crucial role in our model, and does not consider the location choice of firms. Combes and Duranton (2001) also use the model introduced by Pakes and Nitzan

(1983) as a building block. We share the conclusion that weak product market competition leads to more clustering.[7] There are, however, a number of differences between their and our work. Most importantly, we focus on cumulative innovations and trade secret laws whereas Combes and Duranton consider the interaction between product differentiation and the 'absorptive capacity' of firms.

Our paper is also related to the literature on patents and cumulative R&D (Scotchmer, 1991; Green and Scotchmer, 1995). Bessen and Maskin (2000) present a simple model of cumulative R&D, and ask the question of whether patent protection leads to more or to less innovation. The analysis of patent protection is different from that of trade secret protection, but Bessen and Maskin also reach the conclusion that very strong protection of intellectual property may slow down innovation and reduce overall welfare.

2 The Model

2.1 The first period

Consider a world where there are two periods and two entrepreneurs each running a firm. Denote the two firms as A and B respectively. At the beginning of the game, firms must choose irrevocably their locations. The firms can either decide to locate in separate regions or to cluster in the same area. The firms have no marketable product at this stage. After locating, each firm hires a researcher (a worker) to develop a product. The worker is hired from a pool of identical workers. Workers have a reservation wage $\overline{w}$, which is normalized to zero. Workers are wealth-constrained and cannot borrow on the financial markets, so the first-period wage must be non-negative.

Each firm undertakes a R&D project that has an exogenous probability s of succeeding. The successes of the two firms' R&D projects are independently distributed. We assume for time being that R&D is costless, but relax this assumption in section 5. A successful project leads to an innovation that we shall denote as innovation 1. With probability $(1-s)$ the project is unsuccessful, and the firm stays out of the market in the first period. Once the innovation process is resolved, production takes place, the good is sold, and first period profits are realized. The value of marketing innovation 1 as a monopolist is π_1. If both firms develop the innovation, the duopoly profits are $\alpha\pi_1$. The parameter α measures the degree of product market competition, with lower values of α associated with tougher competition. We shall assume that $\alpha \in \left[0, \frac{1}{2}\right]$.

[7] However, thanks to the cumulative nature of knowledge, we find that technology spillovers and clustering also occur when product market competition is very intense, an outcome that never shows up in Combes and Duranton.

2.2 The second period

Firms have in the second period the possibility to develop a new and better version of the product (innovation 2), but only if they have access to the knowledge created when developing innovation 1. R&D is therefore cumulative. This knowledge also allows firms to market innovation 1 if they fail to develop innovation 2. We assume again that R&D is costless and that the probability of success is s (conditional on having the necessary knowledge) and is independently distributed across firms.[8] Innovation 2 is drastic with respect to innovation 1. Hence, a firm endowed with innovation 2 earns monopoly profits both when the rival has innovation 1 and when it has no product at all. Monopoly profits of marketing innovation 2 are π_2, whereas duopoly profits are $\alpha\pi_2$.

We make a number of assumptions concerning the knowledge created in the first period. First, the entrepreneur has access to all relevant information created in his firm. Therefore, if the worker employed in the first period leaves, the entrepreneur can instruct a new worker and continue the R&D activities uninterruptedly. Second, if the two firms have experienced the same R&D outcome in the first period (either success or failure), they have the same knowledge and have no gains from acquiring each other's knowledge. Third, after developing innovation 1 the worker has all the relevant information and is free to use it in the rival firm in the second period. Trade secret laws are thus ineffective. Finally, if an unsuccessful firm hires the successful rival's employee, it immediately acquires all the relevant knowledge.[9] These four assumptions are mainly simplifying, and we will discuss and relax some of them later. Notice that a worker possesses valuable knowledge only if he has worked for the only successful firm in period 1. In all other states of the world, workers are simply paid the reservation wage.

The outcome of the second period depends on the results of R&D activities in the first period. We will therefore describe the game in the second period for the different possible states of the world.

No firm has developed innovation 1 The firms start all over again, and everything is as in period 1 except that firms do not choose location.

[8] In an earlier version we allowed the probability to develop innovation 2 to differ from the probability to develop innovation 1. Since there were no additional insights to be gained, we assumed here that the probabilities are the same.

[9] There is thus an implicit assumption that the R&D activities of the two firms are complementary in the sense that starting from the same knowledge they may come up with different ideas of how to develop innovation 2.

Both firms have developed innovation 1 The two firms aim at developing innovation 2. A firm earns π_2 if it is the only one to develop innovation 2 whereas the rival earns 0. The firms earn $\alpha\pi_2$ if they both succeed and $\alpha\pi_1$ if they both fail.

Only one firm has developed innovation 1 Assume that firm A has developed innovation 1 and firm B has not (the other case is analogous). Firm B would like to hire the employee of firm A to acquire the knowledge necessary to develop innovation 2.[10] We shall assume that this is only feasible when firms are located in the same region, for instance, because relocation costs or informational costs of identifying the 'right' worker are large across regions. This assumption is relaxed in section 5. We need to consider the two subgames where the firms are in the same region and in separate regions.

Suppose that the firms have chosen separate locations. Firm A tries to develop innovation 2 and firm B innovation 1. Firm A drives firm B out of the market if it is successful and earns π_2. If firm A fails, but firm B succeeds, both firms earn $\alpha\pi_1$. Finally, if both firms fail, firm A earns π_1 and firm B earns 0.

Suppose instead that the firms have chosen a joint location. At beginning of the second period, firm B tries to hire the worker that was employed by firm A in the first period. Obviously, firm A would like to retain the worker in order to have a head start in the second period. We model the competition for the worker in the following way. Each firm simultaneously and independently makes a take-it-or-leave-it offer to the worker. The firm who offers more hires the worker and pays the wage that it has offered. Put differently, the hiring process works like a first-price auction. If both firms offer the same wage, we assume that the firm whose valuation of the worker is highest hires him. The tie-breaking rule ensures that an equilibrium in pure strategies exists. We shall focus on the equilibrium in which the firm hiring the worker pays exactly the rival's valuation.[11] Each firm's valuation of the worker depends on its outside options that we shall derive later. If firm A retains the worker, the game continues as in the subgame where the firms are in separate locations. If firm B hires the worker, the game continues as in the state where both firms have developed innovation 1 in the first period.

[10] We disregard licensing contracts, as it is very difficult to license non-patented information. To illustrate the problems that can arise when licensing trade secrets, suppose that the licensee (or the licensor) breaks the contract by reselling the knowledge to an outside firm. Unlike a patent infringement, it is not enough to show that the outside firm used the knowledge in question. The alleging party needs to demonstrate that the outside firm bought the information and did not create it itself, which is obviously very difficult. See also Cheung (1982) for a discussion of these issues.

[11] We disregard equilibria where both firms offer a wage between the lowest and the highest valuation of the worker (and where the firm with the highest valuation hires him), since in these equilibria the firm with the lowest valuation is playing a weakly dominated strategy.

Figure 1 illustrates the game with all the possible states of the world and the actions taken.

[Insert Figure 1]

3 Solving the model

We are now ready to solve the game. Let us start by computing each firm's expected profits if they locate in separate regions. Notice that in this case there is no possibility of labor mobility, so technology spillovers cannot arise. We proceed by backward induction.

Let V_{ij} be firm i's expected profits before the second innovation round is resolved. V_{ij} is a function of the firm's knowledge (subscript i) and the rival's knowledge (subscript j), with $i, j \in \{0, 1\}$ where 1 indicates that the firm in question possesses the knowledge of the first innovation and 0 indicates that it does not. There are four possible states of nature: both firms have the knowledge, no firm has the knowledge, firm A or firm B alone has the knowledge. Expected profits are:

$$\begin{aligned} V_{11} &= s^2\alpha\pi_2 + s(1-s)\pi_2 + (1-s)^2\alpha\pi_1, \qquad (1) \\ V_{00} &= s^2\alpha\pi_1 + s(1-s)\pi_1, \\ V_{10} &= s\pi_2 + (1-s)s\alpha\pi_1 + (1-s)^2\pi_1, \\ V_{01} &= s(1-s)\alpha\pi_1. \end{aligned}$$

The per firm expected profits at time $t = 0$ if firms locate separately are therefore:

$$\Pi_{sep} = s^2[\alpha\pi_1 + V_{11}] + s(1-s)[\pi_1 + V_{10} + V_{01}] + (1-s)^2 V_{00}. \qquad (2)$$

We now focus on the other branch of the game tree in which firms decide to cluster at $t = 0$. As above we proceed by backward induction.

Let us consider the hiring process. Recall that this plays a role only in asymmetric situations. For simplicity of exposition, let us say that firm A has got innovation 1 and firm B has not. Firm A will earn V_{10} if it keeps the worker, and V_{11} if it loses him to firm B. Therefore, firm A's valuation of the worker is $v_A = V_{10} - V_{11}$. Firm B will earn V_{11} if it is successful in poaching the worker, and V_{01} if he stays with firm A. Firm B's valuation of the worker is $v_B = V_{11} - V_{01}$.

Two situations are possible: either $v_A \geq v_B$, and firm A keeps the worker by paying him $w_{ns} = V_{11} - V_{01}$; or $v_A < v_B$, and firm B hires the worker by paying him $w_s = V_{10} - V_{11}$. In the last case, we can talk about technology spillovers, since the knowledge becomes widespread across the industry. Notice that the worker in both cases will be paid more than the wage in the pool. A joint location increases the expected wage of the workers, because firms compete for the knowledge that the workers have accumulated in their prior jobs.

The following result summarizes the outcome of the hiring process:

Lemma 1 *Suppose that the firms are in a joint location, and only one firm has developed innovation 1 in the first period. Technology spillovers arise if and only if* $2V_{11} > V_{10} + V_{01}$.

Proof. The worker moves if $v_A < v_B$. After substituting, this gives the condition reported above. ■

Lemma 1 says that the worker moves only if this increases expected industry profits. After some simplifications, one can rewrite the condition for technology spillovers to arise as follows:

$$\frac{s}{1-s}\frac{\pi_2}{\pi_1}\left[1-2\left(1-\alpha\right)s\right] > \left(1-s\right)\left(1-2\alpha\right)+2s\alpha. \tag{3}$$

Figure 2 illustrates equation (3) as a function of (s, α) for a fixed value of π_2/π_1. From (3), it follows that:

Remark 1 $(1-\alpha)\,s \leq 1/2$ *and* $\pi_2 > \pi_1$ *are necessary conditions for technology spillovers to arise.*

The remark shows that technology spillovers cannot arise unless the value of innovation 2 is larger than that of innovation 1. Furthermore, s needs to be sufficiently low and/or competition sufficiently soft (i.e. α sufficiently high).

The technology spillover condition, equation (3), is a function of α, s, and π_2/π_1. Remember that when the worker moves from firm A to firm B, two opposite effects occur to expected joint profits: (1) both firms have now a chance to develop the second innovation, i.e. the probability to develop the second innovation rises: this effect increases expected joint profits; (2) there is a higher probability that the firms end up in a duopoly situation: this effect decreases expected joint profits due to more competition. The overall result of a change in α, s, and π_2/π_1 can be better understood in terms of these two effects. It follows from Lemma 1 that any change in these parameters that strengthens the first effect, or weakens the second, encourages technology spillovers, because technology spillovers arise only if they increase joint expected profits.

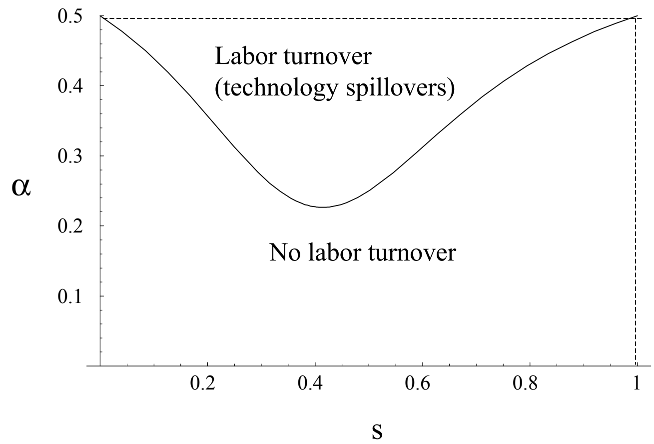

Figure 2. The technology spillover condition as a function of s and α ($\pi_2/\pi_1 = 2$). The line indicates values of s and α such that equation (3) holds with equality. Above the line, $v_A < v_B$ and technology spillovers occur. Below the line, $v_A \geq v_B$ and firm A keeps the worker in equilibrium.

Let us first consider α. There are less rents destroyed by competition if α increases, because competition is softer. This weakens the second effect and technology spillovers arise for a larger region of parameters, as Figure 2 shows.

Let us now consider s. First, notice that when s approaches either 0 or 1, firms are very likely to end up competing on equal footing in the product market, with the first and the second generation product respectively. In turn, this implies that the second effect is stronger, which works against labor mobility. Hence, the parameter space under which technology spillovers take place expands for intermediate values of s. Second, and more important, notice that the marginal increment in the probability to develop innovation 2 of having an additional firm sharing the knowledge of innovation 1 is $s(1-s)$. Such marginal increment is maximized for $s = 0.5$ and tends to 0 as s approaches either 0 or 1. Again the effect of a change in s is non-monotonous, with the parameter space for which technology spillovers take place being the largest for intermediate values of s. Figure 2 illustrates this point.

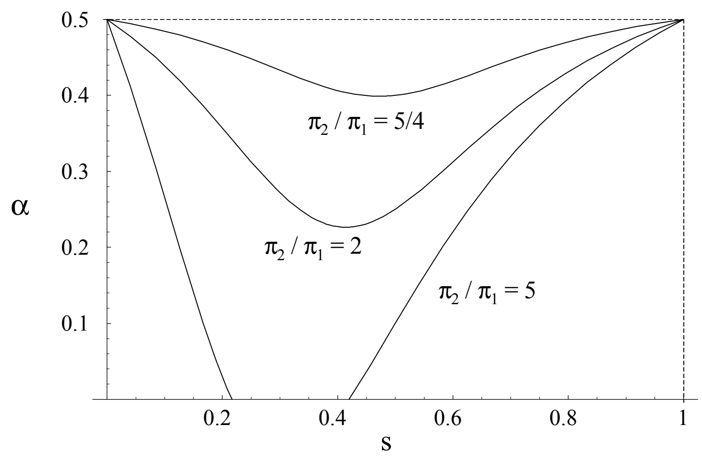

Figure 3. The technology spillover condition for different values of π_2/π_1.

Figure 3 shows the effect of increasing the relative value of the second innovation, π_2/π_1. An increase in π_2/π_1 implies that it is more important in terms of expected joint profits that the second innovation is developed. This strengthens the first effect and increases the region of parameters for which technology spillovers arise. Interesting enough, technology spillovers may occur even if competition among firms is extremely intense. Indeed, figure 2 illustrates how technology spillovers may arise for $\alpha = 0$ if π_2/π_1 is sufficiently high and $s \leq 1/2$. This is worthwhile noting because typically, with strong competition in the product market, the innovator has greater incentives to retain the worker and technology spillovers do not take place (Pakes and Nitzan, 1983; Fosfuri et al., 2001). However, in this case the cumulative nature of innovation allows technology spillovers to materialize even if product market competition is tough.

This last finding is empirically important too, as it suggests that we are more likely to observe technology spillovers when later innovations have a much larger value than earlier innovations. This is the case when the pace of technological innovation within the industry is very intense and a new version of an existing product not only makes the old version completely obsolete but considerably reduces production costs and/or increases the value to the consumers. For instance, a new microchip with expanded computational capability is likely to offer much more value to the consumers and have a larger demand because of a larger array of applications. A somewhat different interpretation of this result is that we are more likely to observe technology spillovers when innovation 1 is based on basic knowledge with little commercial value, whereas innovation 2 is an application with a much larger market and value. For instance, innovation 1 could be a research tool which enables the development of innovation 2, but has not direct commercial value ($\pi_1 = 0$).

The following remark summarizes the comparative statics analysis:

Remark 2 *Technology spillovers arise for a larger parameter space if the relative value of the second innovation is high, competition is soft, and the probability of innovating is intermediate.*

Proof. Using (3), define $\Phi \equiv \frac{s}{1-s}\frac{\pi_2}{\pi_1}\left[1 - 2\left(1-\alpha\right)s\right] - \left(1-s\right)\left(1-2\alpha\right) - 2s\alpha$. The proof follows from: $\partial\Phi/\partial(\frac{\pi_2}{\pi_1}) > 0$ and $\partial\Phi/\partial\alpha > 0$ if the conditions in Remark 1 are satisfied. Furthermore, $\partial\Phi/\partial s > 0$ (< 0) for $s < (>) \underline{s} \equiv 1 - \sqrt{\frac{(1-2\alpha)\frac{\pi_2}{\pi_1}}{1+2\frac{\pi_2}{\pi_1}-2\alpha(2+\frac{\pi_2}{\pi_1})}}$ where $\underline{s} \in (0,1)$. ■

At this stage we are now able to compute the expected profits of the firms when they decide to cluster. The expected profits depend on the result of the hiring process. Hence, we have:

$$\Pi_{clust} = \begin{cases} s^2\left(\alpha\pi_1 + V_{11}\right) + s\left(1-s\right)\left(\pi_1 + 2V_{11} - w_s\right) + \left(1-s\right)^2 V_{00} \\ \text{if } 2V_{11} \geq V_{10} + V_{01}, \\ s^2\left(\alpha\pi_1 + V_{11}\right) + s\left(1-s\right)\left(\pi_1 + V_{10} + V_{01} - w_{ns}\right) + \left(1-s\right)^2 V_{00} \\ \text{otherwise,} \end{cases} \tag{4}$$

where $w_s = V_{10} - V_{11}$ and $w_{ns} = V_{11} - V_{01}$.

We can now analyze the initial location choice of the firms.

Proposition 1 *Firms choose to locate in the same region if and only if*

$$2V_{11} - V_{10} - V_{01} > w_s = V_{10} - V_{11}. \tag{5}$$

Proof. It follows directly from comparing (4) and (2). ■

First notice that the condition for firms to cluster is more stringent than the one driving technology spillovers. Technology spillovers are the only reason to cluster in our model. Therefore, firms would not cluster if technology spillovers could not arise, as a joint location would increase the expected wage of the workers and bring no benefits.[12]

Suppose now that (3) is satisfied, so technology spillovers can arise when firms cluster. The choice to cluster can be seen as an ex-ante agreement to share the knowledge of the first innovation in states where only one firm is successful. Ex-post, technology spillovers reduce the profits of the successful firm and increase the profits of the unsuccessful one. However, as (3) holds, the successful firm loses less than the unsuccessful firm gains, so technology spillovers increase expected joint profits (gross of wages). It follows that technology spillovers also increase ex-ante expected profits, since firms are equally likely

[12] Of course, the firms may cluster for reasons that are not captured in our model; see the discussion in the introduction.

to end up as the successful or the unsuccessful firm. The cost associated with technology spillovers is the higher expected wage earned by the workers due to the competition in the labor market. Condition (5) thus simply states that firms cluster if and only if the benefits from technology spillovers (the left hand side of equation 5) are greater than the additional wage bill (the right hand side of equation 5).

Condition (5) can be rewritten as follows:

$$\frac{s}{1-s}\frac{\pi_2}{\pi_1}\left[1-3\left(1-\alpha\right)s\right] > \left(1-s\right)\left(1-2\alpha\right)+3s\alpha,$$

and is illustrated in Figure 4.

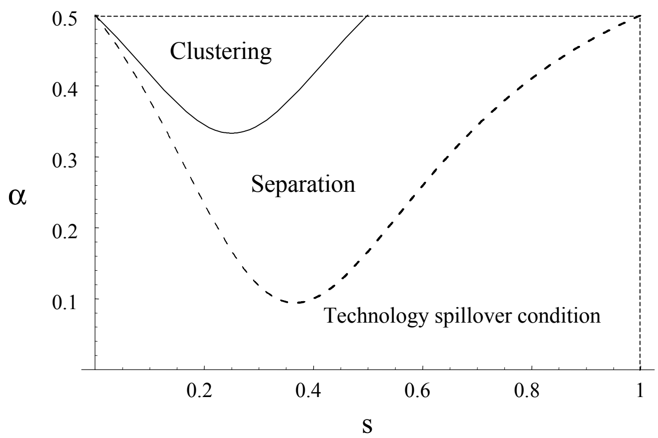

Figure 4. The equilibrium location of the firms ($\pi_2/\pi_1 = 3$). Above the solid line, the firms cluster and below they locate separately. The dashed line indicates the technology spillover condition.

Similarly to condition (3), condition (5) is likely to be satisfied for high values of π_2/π_1 and α and for intermediate values of s. This suggests that local industrial districts with high levels of labor turnover, like Silicon Valley, are associated with industries or sectors where the pace of technological innovation is rapid and leadership is changing frequently. It is less likely that we observe clustering and workers' mobility in more mature and stable industries. Our model would thus predict a positive correlation between of the geographic concentration of R&D activities, growth rate of profits, and volatility of market shares.

4 Trade Secret Laws

Clustering is always welfare improving for the parameters such technology spillovers can arise, because knowledge sharing through labor mobility leads to more innovation and competition. However, as we have shown in the previous section, firms may choose to locate in separate regions even if technology spillovers could occur. The reason is that workers capture a substantial part of the rents generated by the innovation under clustering because of labor market competition.

According to trade secret laws, it is not legal to obtain a rival's trade secrets from one of its former employees.[13] In practice, however, the protection provided by trade secret laws is far from perfect. Firstly, the alleging firm must demonstrate that a trade secret existed. This often proves difficult as the information constituting a trade secret is unknown to the public. Secondly, courts are concerned about workers' freedom to seek new job opportunities. They are therefore reluctant to prevent an employee from working for a rival by granting an injunctive relief or enforcing a very restrictive non-compete covenant. Even if trade secret laws build on the same principles everywhere, there are differences in the extent to which they are enforced. Legal scholars have argued that the protection of trade secrets is particularly weak in California (Gilson, 1999; Hyde, 1998).[14] Furthermore, they claim that this is the key to the observed high rate of labor mobility, and ultimately to Silicon Valley's success as a local industrial district. We argue here that this argument is partially incorrect. It is shown that some degree of trade secret protection not only favors clustering, but it does not reduce technology spillovers. It is only when the protection is excessive that technology spillovers and clustering may be discouraged.

We model trade secret protection by assuming that if a worker brings valuable knowledge to a rival, the hiring firm has to pay the damages established by the court.[15] Denote as $D \in [0, \infty)$ the amount of (expected) damages. Suppose that firm A has developed the first innovation, but firm B has not. Firm A's valuation of the worker is modified as follows: $v_A^{'} = V_{10} - V_{11} - D$, because it receives damages of D if the worker leaves. Firm B's valuation of the worker is $v_B^{'} = V_{11} - D - V_{01}$, since it anticipates the damages. Technology spillovers occur only if $v_A^{'} < v_B^{'}$. Notice that technology spillovers cannot take

[13] The discussion here is based on trade secret protection in the U.S. under the Uniform Trade Secret Act (Budden, 1996; Choate et al., 1987). However, as the laws of trade secrets build on the same principles in most countries, the problems sketched here are also present outside the U.S.

[14] Gilson (1999) argues that California laws are unique in that they do not allow noncompete clauses. Hyde (1998) claims that California laws do not differ significantly from the rest of the U.S., but the enforcement is weaker.

[15] Results would hold unchanged if one assumes that it is the worker (instead of the firm) that has to pay the damages.

place when $D > V_{11} - V_{01}$, since firm B will never be willing to offer more than $v_B^{'}$.

Consider $D \leq V_{11} - V_{01}$. From $v_A^{'} \geq (<) v_B^{'}$, it follows that technology spillovers take place exactly for the same parameter space we derived in section 3. However, there are two important changes. When technology spillovers do not take place ($2V_{11} \leq V_{10}+V_{01}$), firm A pays only $v_B^{'} = V_{11} - D - V_{01}$ to keep the worker. Still, as $w_{ns} = v_B^{'} > 0$ separate locations are preferred by the firms. When technology spillovers do occur ($2V_{11} > V_{10}+V_{01}$), firm A receives D from firm B as damage compensation. Firms' expected profits under clustering are increasing in D, because the damages reduce the rents captured by the workers.

Proposition 2 *As long as trade secret protection is not excessive ($D \leq V_{11} - V_{01}$), firms cluster if and only if*

$$2V_{11} - V_{10} - V_{01} > w_s = V_{10} - V_{11} - D. \tag{6}$$

Furthermore, an increase in the strength of trade secret protection enlarges the parameter space under which clustering takes place, and is always (weakly) welfare improving. However, no protection ($D = 0$) is preferred to excessive trade secret protection ($D > V_{11} - V_{01}$) both by firms and by a hypothetical social planner when condition (5) is satisfied.

Proof. Solving the model as in section 4 for $D \leq V_{11} - V_{01}$, we obtain condition (6), and the first part of the proposition follows. If $D > V_{11} - V_{01}$, technology spillovers cannot take place. If $D = 0$, technology spillovers can arise in equilibrium if (5) is satisfied. Furthermore, when technology spillovers arise in equilibrium, they increase both industry profits, expected wage of the workers, and consumer surplus. It follows that if (5) is satisfied, $D = 0$ is preferred to $D > V_{11} - V_{01}$ by all agents in the economy. ■

Proposition 2 is interesting as it suggests that the effect of trade secret protection can be non-monotonic. Some degree of trade secret protection is always welfare improving because it increases the expected profits of the firms under clustering. This leads in turn to more clustering and technology spillovers. Very strong trade secret protection is worse than no protection as it can prevent technology spillovers from arising in situations where all parties involved would benefit from them.[16][17]

[16] A caveat is in place: we assume here that there are frictions in the bargaining process that prevent the profit maximzing outcome from being realized when $D \geq v_B^{'}$. If we had assumed efficient bargainging (plus some mild, additional assumptions), so the outcome maximizing the joint profits would always be reached, welfare would be increasing in D up to $v_B^{'}$ and constant afterwards. Very strong protection of trade secrets would thus not be harmful.

[17] In this section we have followed the legal doctrine that studies trade secret protection under liability rules. An alternative approach would be using property rules. Under property rules, if the court denies trade secret protection, the worker can freely pass the knowledge to a rival firm. On the other hand, if the court finds a violation of trade secrets, then the alleging firm can exclude the rival completely from

5 Extensions

We consider different extensions of the model presented in section 3. To save space, all proofs have been left out but are available upon request.

5.1 Costly R&D

The simplest way to model the R&D technology is to assume that firms have to invest a fixed amount of money, F, upfront and lump sum, to build up their R&D labs. Further, assume that such decision must be taken simultaneously with the location decision at the beginning of the game.[18] As long as F is not greater than the equilibrium profits derived in section 3, both firms would invest in R&D and the analysis remains unchanged. For higher levels of fixed costs, the market can support only one firm (or none) in equilibrium. Since stronger (but not excessive) trade secret protection increases firms' expected profits, it also enlarges the parameter space under which both firms undertake R&D in equilibrium. Hence, some trade secret protection also stimulates investment in R&D.

More interesting is the case in which location decision and investment in R&D can be postponed at the beginning of the second period. Here, if technology spillovers can arise (i.e. $2V_{11} > V_{10}+V_{01}$), firms may have an incentive to wait and observe the R&D success of the rival before entering the market. Thus, a firm could enter the game only if innovation 1 was developed by the rival firm. The firm would then locate close to the innovating firm and acquire the knowledge of innovation 1 by hiring its worker. The advantage of this strategy is that the firm only pays the fixed cost of entry in situations in which the probability of developing innovation 2, the more valuable innovation, is high.[19] Two new equilibria can arise. First, there is an equilibrium where one firm enters in the first period, and the other firm enters in the second period only if innovation 1 is developed. Second, there is an equilibrium where no firm tries to develop innovation 1 because of the possibility of later entry. Here, entry by the rival in case of success reduces the innovator's profits so much that F cannot be recouped. Therefore, firms do not invest in R&D in the first place. Stronger trade secret protection allows the innovating firm to capture a larger share of the

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the use of the knowledge brought by the worker. Formally, this could be modelled by assuming that with probability p the court decides to protect trade secrets, and with probability $1-p$ it rules in favor of the worker (or the rival firm). Results would not change qualitatively. Details are available from the authors upon request.

[18] An alternative specification is one where firms have to pay a fixed cost in each period, F_1 and F_2 (that might be equal or different), to run and maintain their R&D activities. Although the analysis becomes a bit more complex with a larger range of possible situations, there are no additional insights that one can derive.

[19] Remember, a necessary condition for technology spillovers to arise is that $\pi_2 > \pi_1$, see Remark 1.

rents created by its innovation. Thus, a firm might find it profitable to invest under some parameter constellations for which no firm would have invested with weak trade secret protection. Once again, the conclusion of section 4 - that some protection of trade secrets is beneficial - holds true *a fortiori* once the incentives to invest in R&D are considered.

5.2 No wealth and credit constraints

The workers earn an expected wage above 0 (the reservation wage) in the second period when firms cluster. The workers would therefore be willing to accept a negative first period wage as long as they could survive the first period by consuming initial wealth or borrowing on the capital markets. Of course, the expected wage over the two periods must be non-negative. Suppose that the workers have access to an initial wealth or credit of $w_0 > 0$. Assuming that the total amount of money available for consumption each period should be non-negative, the first period wage cannot be lower than $-w_0$. Solving the game as before, we obtain the following proposition:

Proposition 3 *Suppose that* $2V_{11} > V_{10} + V_{01}$*, so technology spillovers can arise when firms choose a joint location. For* $w_0 < s(1-s)(V_{10} - V_{11})$*, the firms cluster if and only if*

$$s(1-s)\left[2V_{11} - (V_{10} + V_{01}) - (V_{10} - V_{11})\right] + w_0 \geq 0. \tag{7}$$

For $w_0 \geq s(1-s)(V_{10} - V_{11})$*, the workers earn no expected rents, and the firms always cluster. If* $2V_{11} < V_{10} + V_{01}$*, the firms always (weakly) prefer to locate in separate regions.*

We see by comparing (5) and (7) that the firms cluster under a larger parameter space when the wealth constraint is relaxed. The negative first period wage allows the firms to extract (some of) the rents earned by the workers, which makes it more attractive to choose a joint location.

5.3 Finite relocation costs for workers

In section 3, we have assumed that it is prohibitively expensive to hire a worker employed in a different region. Now, we allow for lower levels of relocation costs. Suppose that firm i has to pay a fixed cost $k > 0$ when poaching the worker from firm j located in a different region. Here, there are different cases to consider. First, if $2V_{11} < V_{10} + V_{01}$, technology spillovers do not arise independently of k and firms' locations. The firms thus separate, as the relocation costs reduce the wage of the workers. Second, if $2V_{11} > V_{10} + V_{01} + k$, technology spillovers arise both under clustering and separation. It is thus optimal to cluster to avoid paying the relocation costs. Finally, the most interesting case happens when $V_{10} + V_{01} \leq 2V_{11} < V_{10} + V_{01} + k$. Here, technology spillovers arise only if firms cluster. We need to distinguish between two subcases. If $k > V_{11} - V_{01}$, the lagging firm is not interested in hiring a worker from a firm located in another region. Thus, the analysis developed in section 3 remains unchanged. On the other hand, if $k \leq V_{11} - V_{01}$, the lagging firm is willing to pay up $V_{11} - V_{01} - k \geq 0$ to attract the worker. The model can then be solved as in section 3. We obtain that firms cluster if and only if:

$$
\begin{aligned}
2V_{11} - (V_{10} + V_{01}) &\geq k/2 \text{ when } k < V_{11} - V_{01}, \\
2V_{11} - (V_{10} + V_{01}) &\geq V_{10} - V_{11} \text{ when } k \geq V_{11} - V_{01}.
\end{aligned}
$$

Notice that for low levels of relocation costs, the protection provided by separate locations is stronger the greater is k. Therefore, the profits under separation are increasing in k, which in turn makes clustering less attractive. For high relocations costs, we find again condition (5). Removing the assumption of prohibitively high relocation costs changes the threshold for which firms cluster, but the basic trade-off of the model remains.

5.4 The knowledge is embedded in the worker

We now allow for the possibility that the innovating firm experiences a loss of knowledge when the worker moves to a rival. This could, for example, be because the employee 'hides' some of the relevant knowledge, or because some of the knowledge is tacit and difficult to articulate. Such a loss of knowledge translates in a lower probability to develop innovation 2. To capture this possibility, we assume that if the worker leaves the probability of developing innovation 2 is μs with $\mu \leq 1$. The formal analysis remains basically unchanged with respect to section 3. Suppose that only firm A develops innovation 1. The expected profits of firm A if it loses the worker are now: $V_{11}^A(\mu) = \mu s^2 \alpha \pi_2 + \mu s (1-s) \pi_2 + (1-s)(1-\mu s) \alpha \pi_1$. Similarly, the expected profits of firm B if it hires the worker are: $V_{11}^B(\mu) = \mu s^2 \alpha \pi_2 + s(1-\mu s) \pi_2 + (1-s)(1-\mu s) \alpha \pi_1$. Following the analysis in section 3, it is easy to show that technology spillovers only occur if $V_{11}^A(\mu) + V_{11}^B(\mu) > V_{10} + V_{01}$ where V_{10} and V_{01} are given by (1). Notice that only the LHS of the inequality depends on μ. One can show that the derivative of the LHS of the inequality with respect to μ is always positive. This implies that the larger is μ the larger is the parameter space under which technology spillovers take place. In other words, when the movement of the worker implies a loss of knowledge for the innovating firm, it is less likely that we observe technology spillovers. In the limit for $\mu = 0$, one can show that technology spillovers never take place. As a result, firms do not cluster. Here, the worker's mobility would simply shift R&D capabilities from firm A to firm B without increasing the joint probability of developing innovation 2. Furthermore, some profits would be dissipated because both firms would have innovation 1 and compete in the product market. In sum, our results derived in section 3 rely on knowledge being a public good within the innovating firm.

6 Conclusion

Motivated by the recent debate about the reasons underpinning the success of Silicon Valley, we have studied firms' incentives to cluster in order to benefit from reciprocal technology spillovers. Generally speaking, we find that the story of Silicon Valley, as told by economic geographers and other scholars, is consistent from an economic point of view. Our formal model, however, allows us to pin down the crucial assumptions behind the argument. We find that firms' incentives to cluster are the strongest when the following three conditions are met: 1) technological progress is rapid, so the value of later innovations is high relative to earlier ones; 2) competition in the product market is relatively soft; 3) the probability of a single firm to develop an innovation is neither very high nor very low. Especially the first condition is important for public policy towards industrial clusters. It suggests that the unprecedented growth rate of the information technology is key to the 'job hopping' culture of Silicon Valley that fosters technology spillovers. It may thus be difficult to 'clone' the success of the Valley in industries with slower technological progress.

In addition, weak trade secret protection does not seem to be a prerequisite for clustering and workers' mobility as some legal scholars have recently argued. Perhaps surprisingly, we find that *some* trade secret protection is always beneficial both for firms' profits and for welfare even when R&D is costless, so firms' incentives to invest in R&D are not a concern. The reason is that when firms cluster, some of the rents created by the innovations are captured by the workers because of labor market competition. Trade secret protection reduces those rents and, thus, induces more clustering and technology spillovers. Once the incentives to invest in R&D are considered the benefits of stronger trade secret protection are even greater. It is only when the protection of trade secrets is so strong that no mobility of workers can take place that incentives to cluster and welfare are reduced.

It remains to speculate about possible extensions of the model. A particularly interesting, yet difficult one, is to consider a richer R&D technology where the probability to innovate depends on both the R&D investment of the firm and the effort of the worker. We speculate that in such a framework firms might cluster to provide high-powered incentives to workers, as an innovation is then (sometimes) rewarded with an outside offer and a wage increase.[20] This, as well as other potential extensions of our model, are left for further research.

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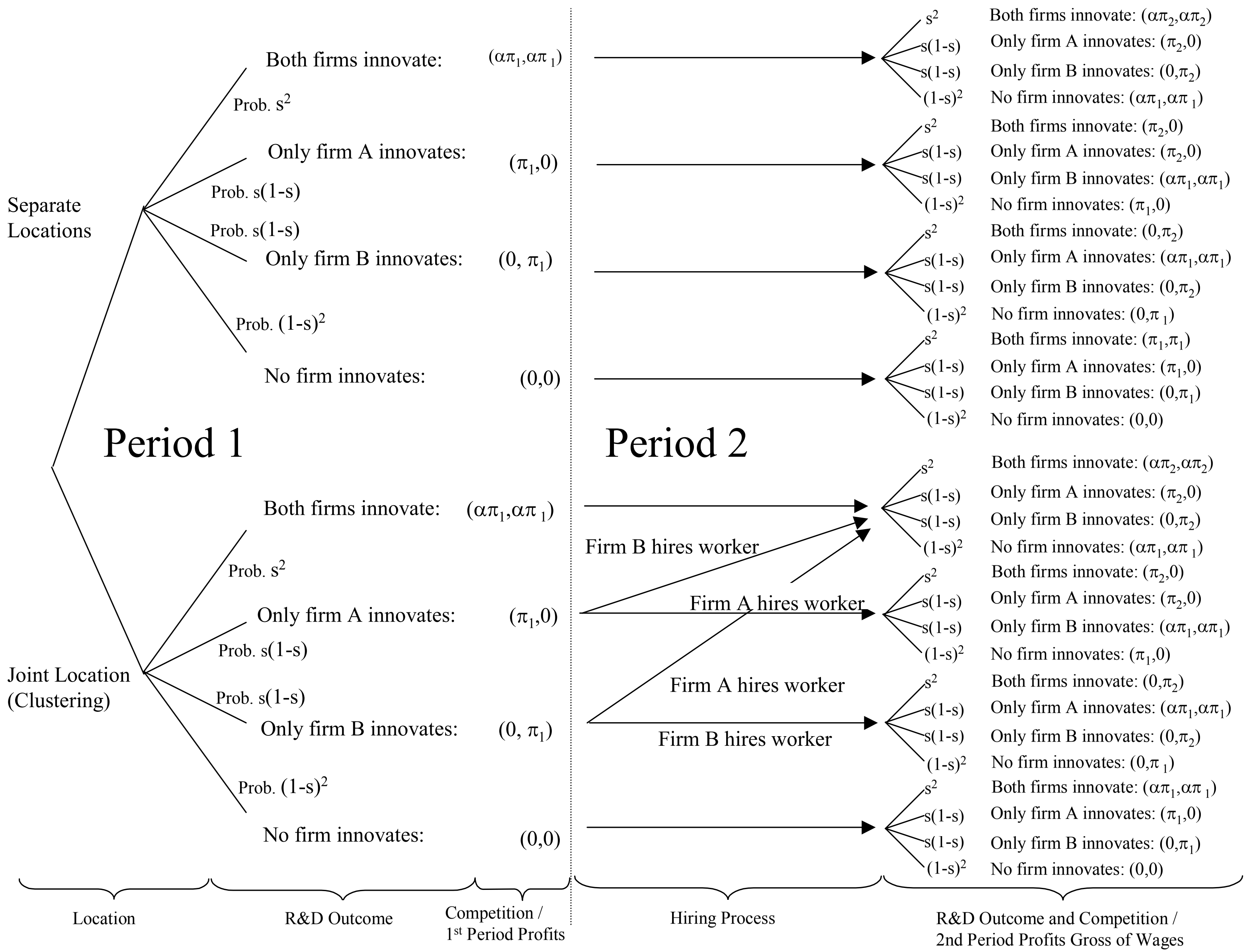

Figure 1: *An illustration of the game with all the different states of the world and the choices of the firms.*