Industry Cohesion & Knowledge Sharing:
Network based Absorptive Capacity

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Abstract

This paper builds on the absorptive capacity model to analyze the implications of relaxing the assumption that information search costs are free. A model is developed and solved to optimize the allocation of research resources between own R&D and search. The results are that search and own R&D efforts are complementary. The optimal allocation depends upon industry characteristics.

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1. Overview

1.1. Introduction

The neoclassical economists make a number of simplifying assumptions. Due to the rigor of the models that can then be built, a number of important insights can be gleaned and, to some extent, be tested. Two of the assumptions – free flowing, costless information (Arrow 1962) and firms communicating exclusively through the price mechanism – have implications to production function models and the resulting investment decisions managers make.

Cohen and Levinthal (1989) relaxed the first assumption when they modeled the importance of knowledge spillovers between firms and the resulting decisions to invest in own knowledge creation in order to develop the absorptive capacity to learn from the spilt knowledge. They showed that in certain situations firms would invest in R&D even if the resulting knowledge were not fully appropriated by the firm in order to learn from other firms. We also have empirical and observational evidence that firms engage in a variety of activities that facilitate joint knowledge production. These activities include joint ventures, research consortia, and publishing activities (Saxenian 1991).

In this paper I extend the Cohen and Levinthal model by relaxing the assumption that information flows freely. Where Cohen and Levinthal showed the implications of firms investing to absorb knowledge, I show the implications of firms investing in search for outside knowledge. Firms invest in search because the information they seek is not freely floating in the atmosphere, and is not captured in the price mechanism.

The results of this paper show that investing in search and own R&D are complementary activities. Investments in search enhance the returns to own R&D efforts, and investments in own R&D efforts enhance the returns to search. Depending upon difficulty of the technological environment, appropriability environment, industry size, and industry cohesiveness, the firm balances investments in own R&D and search to acquire and absorb spilt knowledge in order to maximize the present value of future profits.

This paper is organized as follows. Section one reviews and extends the theory of absorptive capacity, section two develops the model, section three analyzes the model's implications, and section four concludes the paper and offers direction for future research.

1.2. The importance of outside knowledge

Outside sources of knowledge are critical in U.S.-based and international (Japanese) firms (Mansfield 1988; Sakakibara 2002). The same results hold at the industry level (Alcacer et al. 2002), where the ability to exploit external knowledge predicts the decision to locate a new venture. At the organizational level outside knowledge sources are also important and frequently the genesis of innovations (von Hippel 1988). At the project level (Allen 1977), differences in the informal networks of software developers seemed to explain differences in project success due to the presence of gatekeepers that were able to monitor external knowledge sources and translate the knowledge to project members.

The existing literature focuses on the importance of these outside sources of knowledge, but doesn't examine the importance of the network structure of these outside sources. When there are many sources of outside knowledge, which sources the firm selects are critical to what it learns and how it allocates its resources.

1.3. Access to outside knowledge can be formal or informal

Firms learn from each other through formal mechanisms such as Joint Ventures as part of strategic initiatives (Eisenhardt et al. 1996). Depending upon the nature of the innovation, strategic considerations dictate the form of relationship from informal agreements through acquisitions (Teece 1987).

As a result of the importance of outside knowledge, firm boundaries may be determined by the demands for knowledge sharing (Brynjolfsson 1994; Williamson 1975). The knowledge gained from joint ventures is not limited to the specifics of the venture. Overseeing effort and management involvement are channels of learning (Tsang 2002).

March and Simon (March et al. 1958) suggested most innovations result from borrowing rather than invention. von Hippel (1988) suggests that sources of innovation include suppliers, manufacturers and customers. The analysis of temporary profits expected by potential innovators can allow us to predict the functional source of innovation. The economic rent firms appropriate are enhanced by utilizing knowledge, and that more can be gained than lost in most knowledge trading environments.

1.4. <u>Informal relationships and network position facilitates learning</u>

I argue that firms that compete in the same markets or share customers also share knowledge. The knowledge they share may be technical, managerial or market oriented. Industry differences determine the amount of knowledge that can be shared and the mechanisms that firms use to protect valuable intellectual property (Levin et al. 1987). The literature describes the knowledge one firm learns from another as spillover.

Firms share knowledge through attendance at industry trade-shows, visiting common customers, and reading industry publications. They also learn by examining each other's products. The amount firms can learn through observation may be a function of the types of products they produce. Firms that produce easily observed products, such as software, produce more easily absorbed knowledge spillover. Software, semiconductor, and pharmaceutical innovations are both easy to describe, and easy to copy, and are, thus, amenable to protection through patents. Other products or services may be more difficult to replicate, or to protect, and thus use other forms of intellectual property protection. By way of example, compare a steel ingot and a software application.

Software firm A can observe the market's reaction to software firm B's product. Firm A can examine firm B's product, talk to customers, and then replicate certain features or concepts into its own product. We can think of this as firm A learning from firm B. If firms A and B are in complementary markets, firm B suffers no harm from firm A's learning process.

Steel firm A can observe the market's reaction to steel firm B's new innovation. However, steel firm B's innovations may be process oriented and result in a lower price, greater precision (for a milled product), or higher quality. Without access to B's process, A can only learn that B has accomplished a process innovation. While this may spur firm A to find a solution of its own, the amount of informal learning on the part of steel firms is probably less than it is for software firms.

So far I have argued that two firms can learn from each other by sharing a market segment or customers (which may amount to the same thing). If we make the reasonable assumption that knowledge is heterogeneously distributed across firms, then it matters to firm A which firms it is learning from.

Uzzi (1996) found that "the structure and quality of social ties among firms shape economic action by creating unique opportunities and access to those opportunities" in his studies of Broadway Musicals and the New York Garment industry (Uzzi 1996; Uzzi et al. Forthcoming). Firms that have ongoing, stable relationships with a few customers or suppliers (strong ties) and additional relationships with newer partners (weak ties) learn more than either firms that have exclusively strong ties or weak ties. In their study of investment banking firms, Baum et al. (2003) found that firms made strategic decisions in determining who they partnered with in order to improve their network position.

Because firms are not linked to each other in randomly, and because not all firms know the same thing (Simon 1945), the size and shape of the firm's network is a critical component of its knowledge investment decisions. In order to explore the implications of networks on knowledge investments, I have adapted the model presented by Cohen and Levinthal (1989).

2. Model development

The model considers two types of knowledge: the firm's own knowledge developed with internal resources without regard to the external world, and knowledge that originates with competitors and other firms that spillover original, valuable knowledge, and knowledge that originates outside the industry. Although the original model was developed with R&D investments in mind, the model can be generalized to incorporate any type of knowledge development including that performed by marketing research organizations, process development, and intra-firm organization. This generalization is similar to Powell's (1996) inclusion of diverse network ties including formal R&D ties, informal ties, outside investors, clinical trial partners, manufacturing partners, and others in his exploration of network absorptive capacity.

Following Cohen and Levinthal, firms invest in knowledge development to both generate new knowledge and assimilate and exploit existing information. In order to learn something, firms need to know something. Thus, although a firm can concentrate only on internal knowledge development, it cannot only concentrate on spillovers. What a firm can learn from spillovers is a function of both the absorptive capacity of the firm – developed by investing in knowledge development – and the amount of spillover available to be learned. The absorptive capacity is a measure of how well the firm learns. Part of the investment in knowledge development develops the ability to learn. For example, doing in-house research in chemistry enables a firm to better learn from developments in chemistry occurring outside the firm. The amount of spillover to be learned is a function of the barriers to appropriability (trade secrets, patents, etc.), the visibility of the innovations (certain products or processes are easier to replicate than others), and the amount of innovation, which may be limited by opportunity conditions.

In traditional economic literature, information in the public domain was assumed to be free, and costlessly absorbed (Arrow 1962). Cohen and Levinthal effectively argued that if such information was costlessly absorbed, it was only because firms had invested in absorptive capacity, which wasn't costless. The model that they developed is:

$$z = M + \gamma(\theta \sum_j M_j + \mathrm{T})$$

Central to their model is the determination of the firm's stock of knowledge. z is the addition, in period t, to the focal firm's stock of knowledge. They assume that z increases a firm's gross earnings, $\prod$, $\frac{\partial \Pi}{\partial z} \rangle 0$, but at a diminishing rate, $\frac{\partial^2 \Pi}{\partial z^2} < 0$. M is a firm's investment in knowledge creation; γ is the fraction of knowledge in the public domain that the firm is able to assimilate and exploit, and represents the firm's absorptive capacity; θ is the fraction of intra-industry spillovers; M_j is the investment made by other firms, and T is the level of extra-industry knowledge. $0 \leq \gamma \leq 1$ and $0 \leq \theta \leq 1$. If γ equals zero, the firm has no absorptive capacity and only learns by doing its own research. If γ has a value of one, the firm learns everything that is spilt. If θ equals zero, no knowledge is spilt. Either other firms perform no knowledge creation, or they have perfect knowledge appropriability. If θ equals one, all the knowledge developed by other firms enters the public domain.

A firm's investment in M increases γ, although at a diminishing rate. The effect of M on γ is a function of the type of knowledge being spilt, and how important internal knowledge investments are to the ability of the firm to absorb the spilt knowledge (i.e., difficulty of learning). The impact of z on $\prod$ is a function of technological and other opportunities.

Each firm has a similar function and, in order to model a symmetric Nash equilibrium in knowledge investment levels, Cohen and Leventhal assumed that an increase in knowledge on the part of one firm, j, decreases the focal firm's profit and marginal benefit from increasing its knowledge level. The solution to the model shows that, depending upon the fractions γ_i and θ, a firm would still invest in knowledge creation even if knowledge could be appropriated.

However, by changing one assumption and adding one, and generating a new model, we can get additional insights. The implicit assumption in the earlier model was that information flowed freely. It may not be costless to absorb, but the original model did not incorporate a search cost. In the new model, the cost of accessing a firm's private or public information is non-negligible. The cost of absorbing spillovers is not just the cost of developing the absorptive capacity. The knowledge doesn't just accrue to the firm once the absorptive capacity has been developed. Rather, there is a cost to access the knowledge held by the other firms. The new assumption is that firms form formal and informal networks in which knowledge is shared. Firms do not communicate exclusively through the price mechanism. For example, they examine each other's products, talk to each other's customers, and form marketing and product development relationships.

This brings us to the new model of the firm's knowledge acquisition function. The firm is interested in maximizing the present value of future profits, Π. $\Pi = \sum_{t=0}^{\infty} \pi(t)u(t)$, where π(t) is profit in time t, and u(t) is the appropriate discount rate. Therefore, the firm's objective is to maximize π(t). I've defined $\pi(t) = \pi(Z_t, K_t, L_t)$, where Z_t is the stock of knowledge in the last period, and K and L are capital and labor stocks, respectively. Therefore, the firm will invest in order to maximize Z_t, subject to the constraint that the change in present value of future profits due to the present value of knowledge investments, I, is positive, $\frac{\partial \Pi}{\partial I} > 0$. In order to maximize Z_t, the firm maximizes $\frac{\partial Z}{\partial t} = z$.

The updated, network absorptive capacity model is $z = M + \gamma(\theta \sum_{j}^{J} \left(\chi^{j} \cdot Q_j \right) + T)$, $0 \leq \chi, \gamma, \theta \leq 1$. As in the earlier model, absorptive capacity, γ is a function of the investment that the firm makes in its own knowledge creation and the difficulty of learning additional knowledge. If the firm faces a technological environment in which all knowledge is tacit, the firm will have to invest considerable sums in its own knowledge development in order to learn from firms and other outside sources. If the firm faces a technological environment, however, in which all knowledge is codified, the firm will need to invest very little in order to learn from those same sources. In order to simplify the model, I assume that, because the firm's technological environment is dynamic, absorptive capacity is a function only of current-period investments. The firm cannot rely upon past investments in knowledge development in order to maintain its absorptive capacity. Thus, $\gamma = \gamma(M_t, \delta)$, where δ represents technical difficulty or the difficulty of learning the spilt knowledge.

Industry spillover, θ, reflects the intellectual property appropriability regimen for the industry. If the industry's technology is unobservable, hard to replicate, and non-transferable, θ will be very low. If the industry's technology is easily observed, replicated, and transferable, and not well protected by patent or other legal safeguards, θ will be very high. θ is assumed exogenous to the firm.

Recognizing that knowledge does not flow without friction, search cost, χ^j, represents the effectiveness of accessing firm j's knowledge. Search represents a wide range of activities from attending common trade association meetings, visiting a firm's website or reading its product literature, to reverse engineering products and entering into joint ventures. I assume that search effectiveness is a function of what the focal firm invests in search, and the shape of the industry network. The greater the resources a firm expends in accessing another firm, the more it will learn, though at a decreasing rate. The greater the cohesiveness of the industry network, the more each firm will know the knowledge of other firms. To the extent that each firm knows what all the other firms know, the focal firm need only visit a few firms to know what they know. I model $\chi^j = \chi(\alpha, \phi)$, where α represents the total investment in search and ϕ represents shape of the network, network cohesion, and thus affects the quantity and quality of knowledge learned, relative to what's known, by accessing firm j.

In this model, network cohesion, ϕ, does not represent a specific network measure as might be calculated by network researchers (Baum et al. 2003; Freeman et al. 1991; Powell et al. 1996; Uzzi 1996). Rather, it reflects the idea that firms are not independent actors interacting only through the market place where the only communication is the price mechanism. Firms are connected to each other through a variety of formal and informal mechanisms. The cohesion variable represents the amount of knowledge sharing between firms due to each firm's absorptive capacity, industry spillovers, and investment in search. Network cohesion is both a factor in the effectiveness of search and the result of investments in search. If cohesion is low, the focal firm will need to seek each firm in the industry to have access to the industry's spillovers. If cohesion is very high, the focal firm need only seek a single firm to access the industry's spillovers. In the short term, cohesion is assumed exogenous. However, in the long run, cohesion is affected by the search actions of all the firms in the industry.

Q_j represents the same type of investment as M, except it represents the investments other firms make in their knowledge development. Although I assume all other firms invest the same amount, this amount may be different than that which is invested by the focal firm. T represents the knowledge available outside of institutional control such as periodicals and journals.

If γ is zero, the firm has no absorptive capacity and only learns by doing its own research. If γ has a value of one, the firm learns everything that is spilt. If θ has a value of zero, no knowledge is spilt. Either other firms perform no knowledge creation, or they have perfect knowledge appropriability. If no investment is made in search, χ, investments in absorptive capacity are irrelevant. Similarly, if there are many firms in an industry with little cohesion, search cost may be so prohibitive that firms are protected by anonymity and need not engage in efforts to restrict spillovers.

In order to analyze the decision making process for the focal firm, I assume the firm wants to maximize z_t subject to a budgetary constraint, $C \geq r \cdot M + s \cdot \alpha$, where C is the budget constraint, r is the price of a unit of own-knowledge development, M, and s is the price of a unit of search, α. Using the function for increasing knowledge, z, as the objective function, and the constraint defined above, the firm can create a Lagrangian function and identify the point where it is maximized. In order to do this, the functions, γ and χ, must be given specific functional forms.

For both absorptive capacity and knowledge search I assume the functional forms are exponential, $(1-e^{-x})$. This form has the property that it is always bounded between zero and one, and as x gets larger the expression approaches one at a decreasing rate. $\frac{\partial f}{\partial x} > 0, \frac{\partial^2 f}{\partial x^2} < 0$.

For absorptive capacity I set $\gamma = (1-e^{-M/\delta}), \frac{\partial \gamma}{\partial M} > 0, \frac{\partial \gamma}{\partial \delta} < 0$. Increased investment in own knowledge increases absorptive capacity while increased difficulty, δ, decreases absorptive capacity. For knowledge search I set $\chi = (1-e^{-\alpha/(1+J^2(1-\phi))}), \frac{\partial \chi}{\partial \alpha} > 0, \frac{\partial \chi}{\partial \phi} > 0, \frac{\partial \chi}{\partial J} < 0$. Investments in search increase search effectiveness. However, the investment in search, α, are shared across all the other firms in the industry, J. If the number of firms in the industry increases, less search resources are available for each firm, decreasing search effectiveness. Increased cohesion, ϕ, increases the effectiveness of search since fewer firms need to be visited to have access to the industry's spillovers since the firms share an increasing amount of knowledge. If entering firms increase cohesion, the result may be increased search effectiveness. The exact link between firm entry and industry cohesion is not modeled in this paper.

The number of firms, J, in function χ is squared to reflect the observation that as the number of firms grows, the search investment is more widely shared, and knowledge is more widely distributed. A practical consideration also governs the decision to square J. $\sum_j^J \left(\chi^j \cdot Q_j\right) \equiv J(\chi^j \cdot Q_j)$, if we assume that all other firms in the industry make the same investments and that the focal firm searches all firms. The $\lim_{J\to\infty} J(1-e^{-1/J}) = 1$ and $\lim_{J\to\infty} J(1-e^{-1/J^2}) = 0$. If the industry expands while the search investment is held constant, should the returns to search increase or decrease? The logical answer is that there should be decreasing returns to spreading the search investment more thinly.

If we assume that all firms make similar investment decisions, the focal firm invests equally across all firms in the industry, and that network cohesion is uniform, then $z = M + \gamma(\theta \cdot J \cdot \chi^j \cdot Q_j + T)$. The firm's objective is to maximize z subject to $C \geq r \cdot M + s \cdot \alpha$. The Hessian of the objective function, z, with sign minus, is

$$\begin{pmatrix} \frac{e^{-\frac{\alpha}{1+J^2(1-\phi)}}\left(1-e^{-\frac{M}{\delta}}\right) JQ\theta}{\left(1+J^2(1-\phi)\right)^2} & -\frac{e^{-\frac{M}{\delta}-\frac{\alpha}{1+J^2(1-\phi)}} JQ\theta}{\delta\left(1+J^2(1-\phi)\right)} \\ -\frac{e^{-\frac{M}{\delta}-\frac{\alpha}{1+J^2(1-\phi)}} JQ\theta}{\delta\left(1+J^2(1-\phi)\right)} & \frac{e^{-\frac{M}{\delta}}\left(\left(1-e^{-\frac{\alpha}{1+J^2(1-\phi)}}\right) JQ\theta+\tau\right)}{\delta^2} \end{pmatrix}$$

. The product of its Eigenvalues is

$$-\frac{e^{-\frac{2M}{\delta}+\frac{\alpha}{-1+J^2(-1+\phi)}} JQ\theta\left(\left(1-e^{M/\delta}+e^{\frac{M}{\delta}+\frac{\alpha}{-1+J^2(-1+\phi)}}\right) JQ\theta+\tau-e^{M/\delta}\tau\right)}{\delta^2\left(-1+J^2(-1+\phi)\right)^2}$$

. If this expression is positive, the Eigenvalues have the same sign and we can test for convexity. Unfortunately, depending upon the actual parameters chosen, the expression evaluates to positive or negative numbers. Therefore, the objective function is neither convex nor concave and the KKT (Karush-Kuhn-Tucker) conditions are necessary, but not sufficient, for an optimal solution.

The Lagrangian for this optimization problem is:

$L[] = M + \gamma(\theta \cdot J \cdot \chi^{j} \cdot Q_j + T) + \lambda(C - (\mathrm{r} \cdot \mathrm{M} + \mathrm{s} \cdot \mathrm{a})$, which simplifies to

$\mathrm{M} + (\mathrm{C} - \mathrm{M\,r} - \mathrm{s}\,\alpha)\,\lambda + \left(1 - e^{-\frac{M}{\delta}}\right)\left(\left(1 - e^{-\frac{\alpha}{1+J^2(1-\phi)}}\right) J\,Q\,\Theta + \tau\right)$. The KKT conditions are:

$$\left\{\left\{M \geq 0,\ 1 - r\,\lambda + \frac{e^{-\frac{M}{\delta}}\left(\left(1 - e^{-\frac{\alpha}{1+J^2(1-\phi)}}\right) J\,Q\,\Theta + \tau\right)}{\delta} \leq 0\right\},\right.$$

$$\left.\left\{\alpha \geq 0,\ -s\,\lambda + \frac{e^{-\frac{\alpha}{1+J^2(1-\phi)}}\left(1 - e^{-\frac{M}{\delta}}\right) J\,Q\,\Theta}{1 + J^2(1-\phi)} \leq 0\right\},\ \{\lambda \geq 0,\ C - M\,r - s\,\alpha \geq 0\}\right\}$$ and

$$\left\{M\left(1 - r\,\lambda + \frac{e^{-\frac{M}{\delta}}\left(\left(1 - e^{-\frac{\alpha}{1+J^2(1-\phi)}}\right) J\,Q\,\Theta + \tau\right)}{\delta}\right) == 0,\right.$$

$$\left.\alpha\left(-s\,\lambda + \frac{e^{-\frac{\alpha}{1+J^2(1-\phi)}}\left(1 - e^{-\frac{M}{\delta}}\right) J\,Q\,\Theta}{1 + J^2(1-\phi)}\right) == 0,\ (C - M\,r - s\,\alpha)\,\lambda == 0\right\}$$

After solving for lambda, and substituting the results back, I have two equations in terms of M and α.

$$\left\{\alpha\left(\frac{s\left(-1+\frac{e^{-\frac{M}{\delta}}\left(\left(-1+e^{\frac{\alpha}{-1+J^2(-1+\phi)}}\right)JQ\theta-\tau\right)}{\delta}\right)}{r}+\frac{e^{\frac{\alpha}{-1+J^2(-1+\phi)}}\left(1-e^{-\frac{M}{\delta}}\right)JQ\theta}{1-J^2(-1+\phi)}\right)==0,\right.$$

$$\left.\frac{(C-Mr-s\alpha)\left(-1+\frac{e^{-\frac{M}{\delta}}\left(\left(-1+e^{\frac{\alpha}{-1+J^2(-1+\phi)}}\right)JQ\theta-\tau\right)}{\delta}\right)}{r}==0\right\}$$

Since a closed form solution of M and α is not available, I used simulations to illustrate the results. Figure 1 shows the allocation to search cost, α, that maximizes knowledge gain as the number of firms is increased. As the number of firms in the industry increases, the focal firm increases its expenditure in learning what they know. However, if the cost of search is too great, the firm stops investing in search and devotes all of its resources towards own knowledge development.

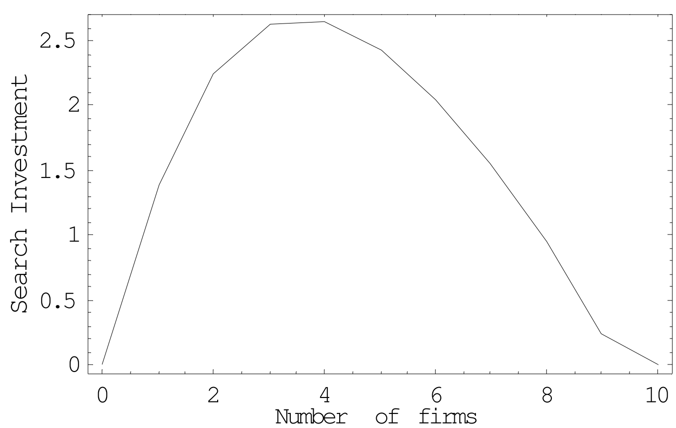

Figure 1: Search investment as a function of the number of firms. $\alpha(J)$.

$\delta = 0.5$, $\theta = 0.7$, $\phi = 0.5$, $Q = 1.0$, $T = 1.0$, $C = 1.0$, $r = 1.0$, and $s = 0.1$.

Figure 2 shows the optimal search investment as network cohesion is varied. As the cohesion increases the focal firm is induced to invest more in search and less in own knowledge development. However, as the industry becomes more cohesive, the focal firm doesn't need to invest as much in search in order to maximize knowledge development.

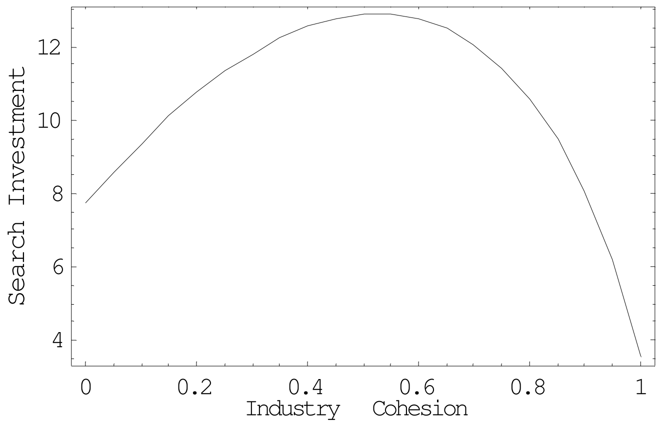

Figure 2: Search investment as a function of network cohesion. α(ϕ).

J = 5, δ = 0.5, θ = 0.7, ϕ = 0.5, Q = 1.0, T = 1.0, C = 1.0, r = 1.0, and s = 0.1.

In order to solve the optimization problem mathematically, the functional forms for absorptive capacity and search cost needed to be simplified. I used the following because they produced similar curves to the exponential forms, and proved easier to work with mathematically: $\gamma = M \cdot (1-\delta), \frac{\partial \gamma}{\partial M} > 0, \frac{\partial \gamma}{\partial \delta} < 0, 0 \le M \le 1$ and

$\chi = \alpha/(1+J^2(1-\phi)), \frac{\partial \chi}{\partial \alpha} > 0, \frac{\partial \chi}{\partial \phi} > 0, \frac{\partial \chi}{\partial J} < 0, 0 \le \alpha \le 1$. The Hessian of the utility function, z, is

$\begin{pmatrix} 0 & \frac{JQ(1-\delta)\theta}{1+J^2(1-\phi)} \\ \frac{JQ(1-\delta)\theta}{1+J^2(1-\phi)} & 0 \end{pmatrix}$ Its Eigenvalues are $\begin{pmatrix} -\sqrt{\frac{J^2Q^2(-1+\delta)^2\theta^2}{(-1+J^2(-1+\phi))^2}} \\ \sqrt{\frac{J^2Q^2(-1+\delta)^2\theta^2}{(-1+J^2(-1+\phi))^2}} \end{pmatrix}$. Since one Eigenvalue is positive, and one is negative, the utility function is neither concave nor convex. The Lagrangian using the linear functional forms simplifies to:

$L[\,] = M + (C - Mr - s\alpha)\lambda + M(1-\delta)\left(\tau + \frac{JQ\alpha\theta}{1+J^2-J^2\phi}\right)$ and has three solutions:

$$\left\{\{M \to 0,\ \lambda \to 0\},\ \left\{M \to \frac{C}{r},\ \lambda \to \frac{1+\tau-\delta\tau}{r},\ \alpha \to 0\right\},\ \left\{M \to \frac{C J Q(-1+\delta)\theta - s(-1+(-1+\delta)\tau)(-1+J^2(-1+\phi))}{2 J Q r(-1+\delta)\theta},\ \alpha \to \frac{C J Q(-1+\delta)\theta + s(-1+(-1+\delta)\tau)(-1+J^2(-1+\phi))}{2 J Q s(-1+\delta)\theta},\ \lambda \to \frac{C J Q(-1+\delta)\theta - s(-1+(-1+\delta)\tau)(-1+J^2(-1+\phi))}{2 r s(-1+J^2(-1+\phi))}\right\}\right\}$$

Depending upon the actual parameters in the equations, one of these equations will provide the optimal solution. The first two solutions are trivial. There will be some situations in which the entire budget should be invested in search. There will be other situations in which the entire budget should be allocated to own knowledge development. In the third case there is an optimal allocation between the two. It is for this case that additional analysis will be done. Since the firm is always better off, in this model, investing the entire budget in either search or own knowledge, the analysis will be limited to changes in search investment.

3. Comparative Statics Analysis

I will now consider the impact of exogenous changes to technological difficulty, spillovers, search cost (price), network cohesiveness, and industry size to the allocation decision between search and own knowledge development. I will also show that investments made to increase search effectiveness are complementary to own knowledge investments.

As the technical environment becomes more challenging, the firm will spend more on own knowledge and less on search in order to increase or maintain absorptive capacity.

$$\partial_\delta \alpha == \frac{-1 + J^2(-1+\phi)}{2 J Q(-1+\delta)^2 \theta} < 0$$

As spillovers increase, the firm will increase its investment in search, and decrease its investment in own knowledge development. Previous research (Arrow 1962) has described the corresponding decrease in own knowledge development in order to minimize the benefit to competitors. In this paper, spillover increases shift the spending allocation.

$$\partial_\theta \alpha == -\frac{(-1+(-1+\delta)\tau)(-1+J^2(-1+\phi))}{2 J Q(-1+\delta)\theta^2} > 0$$

As the amount of research performed by other firms in the industry increases, the focal firm will decrease its own research and increase the resources directed towards search.

$$\partial_Q \alpha == -\frac{(-1 + (-1+\delta)\ \tau)\ (-1 + J^2\ (-1+\phi))}{2\ J\ Q^2\ (-1+\delta)\ \theta} > 0$$

As the cost of search decreases, due to, for example, changes in the cost of communication, the Internet, or other improvements in information economics, the firm will perform additional search. Similarly, as the cost of search increases, due to a change in industry norms for example, the amount of search will decrease.

$$\partial_s \alpha == -\frac{C}{2\ s^2} < 0$$

A decrease in telecommunication, information sharing, and search costs increases the number of other firms the focal firm can access for spillovers. Such a reduction increases the knowledge gained from spillovers and increases the returns to absorptive capacity, thereby increasing the incentive to invest in knowledge. A decrease in telecommunication and information sharing costs enables stronger, or at least cheaper, ties between partners in formal networks, and increases the number of information sources, customers and markets that can be accessed through informal networks (such as the one created by partaking of spillovers) (Bakos 1997; Bakos 1998). Similarly, changes in information economics, principally the Internet, have decreased the cost of locating new sources of knowledge and marketing products into new markets. Markets traditionally separated are more integrated. As a result, not only does the model suggest that more firms will be accessed due to a lower cost of access, but the returns to network position and absorptive capacity will increase. The model would also suggest that a decrease in access costs would also decrease the cohesiveness threshold at which point both network position and absorptive capacity become more cost effective than own knowledge investment.

As the amount of external information flowing to the firm without search increases, the firm will invest less in search. In this model, extra industry knowledge and industry knowledge are substitutes, and the extra industry knowledge doesn’t have a cost associated with it. This type of information can perhaps be thought of arriving in the form of academic and industry journals, where the cost of subscription is viewed as negligible.

$$\partial_\tau \alpha == \frac{-1 + J^2\ (-1+\phi)}{2\ J\ Q\ \theta} < 0$$

As the number of firms in the industry increases, the response on search expenditure is dependent upon the number of firms already in the industry. The value of the derivative is positive for some values of J, and negative for others. When the number of firms in the industry is small, the increase in available knowledge prompts additional search. However, when the number of firms is large, the increased knowledge is more than offset by the increasing ineffectiveness of search.

$$\partial_J \alpha == \frac{(-1 + (-1 + \delta)\ \tau)\ (1 + J^2\ (-1 + \phi))}{2\ J^2\ Q\ (-1 + \delta)\ \Theta}$$

$$\partial^2{}_J \alpha == \frac{1 + \tau\ (1 - \delta)}{-J^3\ Q\ \Theta\ (1 - \delta)} < 0$$

As the network of firms that spill knowledge grows, the cost of accessing that knowledge grows too. Firms make decisions as to whether or not to learn from other firms. Firms also make decisions that affect their strategic position within their industry. Position within a network confers strategic value and access to information (Baum et al. 2003; Uzzi 1996). The better the focal firm's position is relative to the firms spilling knowledge, the better it will do in gaining access to that spillover. The better access may result from working on joint projects, working with the same customers, or linking to the right mix of firms.

Comparing this new model to the original Cohen and Levinthal model, we see that if the cost of search is small, or the industry is very cohesive, the results are the same. However, if *J* is large, the industry is not cohesive, and search costs are non-negligible, we can predict a low investment in absorption capacity and access even if the spillovers are high.

The model gives mathematical support to Uzzi's (1996) explanation as to why small worlds make a difference. By increasing ϕ, the small world increases the effectiveness of search and incents the firms within a small world to make investments in absorptive capacity and increase their knowledge base over their competitors that are not so positioned.

$$\partial_\phi \alpha == \frac{J\ (1 + \tau\ (1 - \delta))}{2\ Q\ \Theta\ (1 - \delta)} > 0$$

As the cohesiveness of the industry increases, the focal firm increases its investment in search. The earlier argument was that cohesiveness reduced the number of firms that the focal firm had to visit in order to access the same amount of information. The increased expenditure suggests that another change is also taking place. The quality of the search may be changing from informal, inexpensive searches to more formal, strategic searches through such mechanisms as joint ventures and strategic alliances. Given the non-random partnering in Baum (2003), we can infer firms invest in network position in order to increase access to spillover knowledge.

3.1. <u>Direct effect of network position</u>

The model suggests that by improving its network position, its effective ϕ, the firm increases the knowledge it acquires from external sources. By improving access to other firms' knowledge, the firm increases its own knowledge stock, and, thus, increases its profitability. By improving its network position – increasing ϕ - the firm also increases the returns to γ, absorptive capacity. A firm investing in network position has an incentive to also invest in absorptive capacity and increase its investment in knowledge.

There may also be conditions in which an industry increases θ and works to reduce search cost, s, in order to increase z and achieve greater profitability. Increased spillover leads to increased incentive to invest in absorptive capacity and can actually increase R&D expenditures. The implication is that, although increasing spillovers is not something any particular firm would want to do, it doesn't necessarily lower R&D. If a firm traded appropriability for reduced search cost, could it increase profits? Does the open source movement trade appropriability for knowledge access?

3.2. <u>Direct effect of increased cohesiveness</u>

The model suggests that when the level of cohesiveness is low and the number of firms is high – many unlinked firms – the returns to absorptive capacity are low. There is little incentive to invest in search or absorptive capacity. Moreover, the model suggests that issues of protecting intellectual property are of little importance unless the firms interested in protecting such property are linked. The firms are protected by their anonymity. Firm creation – an increase in J – that decreases cohesiveness, by, for example, disrupting established relationships, decreases the value of existing network access and absorptive capacity. If the network doesn't become too fragmented, there is every incentive to invest in networking to rebuild network position. However, if exogenous changes to the network, caused by "the winds of creative destruction" (Schumpeter 1942) or political upheaval, the incentive to invest in network position, absorptive capacity, and knowledge may be, reduced.

The argument is that the firm invests in internal knowledge, absorptive capacity, and network position so that the marginal returns from each source of knowledge is equal. Each of these inputs substitutes for knowledge creation. A change that lowers the cost of any input, changes both the balance between the inputs and the total amount consumed. Similarly, any change that increases the cost of an input changes the balance and overall consumption level. A change that disrupts the network, in effect, increases the cost of a unit of knowledge due to decreased network cohesiveness. The value of absorptive capacity then decreases, and the cost of a unit of knowledge increases. If the cost of producing knowledge internally were less than the cost of capturing spillovers, the firm would have balanced its investment portfolio so that the marginal costs were equal.

If, instead of exogenous network destruction, cohesiveness increases among the firms due to increased competition and complementary goods, the firm would face two forces. Profits would be constrained due to the additional competition and due to the increased appropriation of spillover. Yet, there would be increased incentives to invest in search and absorptive capacity. Again, it's not clear what the outcome would be. A small amount of additional competition might only serve to depress profits without offering appropriability of spillover opportunities. As competition increases, firms invest in networking and absorption and knowledge creation. The rents on the new knowledge might be greater than the original loss of profitability?

3.3. Complementarities

Utilizing the exponential functional forms for absorptive capacity and search, we can see that although the second derivatives are negative, suggesting diminishing returns to search investments, the cross derivative between search and own knowledge is positive.

$$\partial_\alpha z == \frac{e^{-\frac{\alpha}{1+J^2(1-\phi)}}\left(1-e^{-\frac{M}{\delta}}\right) J\,Q\,\theta}{1+J^2(1-\phi)} > 0$$

$$\partial^2_\alpha z == -\frac{e^{-\frac{\alpha}{1+J^2(1-\phi)}}\left(1-e^{-\frac{M}{\delta}}\right) J\,Q\,\theta}{(1+J^2(1-\phi))^2} < 0$$

$$\partial_{\alpha,M} z == \frac{e^{-\frac{M}{\delta}-\frac{\alpha}{1+J^2(1-\phi)}} J\,Q\,\theta}{\delta\,(1+J^2(1-\phi))} > 0$$

This result has interesting implications. Analogous to the earlier observation that certain knowledge producing activities were performed to increase absorptive capacity even if the knowledge generated spilt over, I argue that certain knowledge producing investments may serve no purpose other than to facilitate search. Firms may make knowledge development investments in order to develop stronger links with a greater number of inter- and intra-industry partners in order to gain better access to network knowledge. As a result of possibly spilt knowledge investments, other firms may seek the focal firm for partnership activity, and potential partners might better receive the focal firm.

4. Conclusion

I have argued that firms invest in own knowledge development, absorptive capacity, and search in order to maximize knowledge creation, their knowledge stock, and their profitability. Firms allocate their knowledge budget between own knowledge development and search investments according to industry-specific parameters that include the difficulty of the technological environment, the appropriability regimen, the amount of spillovers, the number of firms in the industry, and industry cohesiveness.

Search and own knowledge development are complementary. Firms invest in knowledge creation not only to pursue direct product and process innovation, but also to develop and maintain network position. It is through search and network position that firms are able to access information that they can assimilate and exploit through their absorptive capacity. R&D and other knowledge creating activities have a triple role: increase new knowledge, absorb external knowledge, and gain access to external knowledge sources. In addition to barriers to spillover, and the amount of spillover, the shape of the network and a firm's position within it determine how a firm allocates its investment resources.

Much of the economic research considers only industry concentration, size, appropriability considerations, and technological opportunity in explaining investment decisions. I suggest, however, that this assumes that firms operate as independent entities through the market, and not as interdependent, interrelated entities that form distinct networks. Firms, however, do form networks, and these networks are not random. A firm's position within its network(s) gives it access to information that, were it not in the network, it would not have. Free information does not flow freely. Thus, network position mediates the absorption of external information. Moreover, based upon the model, I hypothesis that firms will pay for access to the network by committing R&D dollars to network positioning projects. I suggest that the Open Source movement can be partly explained in these terms.

The observations flowing from this model shed new light on additional research questions. For example, do firms invest in diversification strategies to increase knowledge even if the projects themselves lose money? Can certain product or joint venture strategies be characterized as exploration of other firms, and not as exploration solely of product markets? Do own knowledge development strategies differ depending upon the amount of complementary search? How are information economics changing search strategies?

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