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## « Network Formation and Strategic Firm Behaviour to Explore and Exploit »

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# Network Formation and Strategic Firm Behaviour to Explore and Exploit

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### Abstract

The aim of this paper is to investigate the effect of technological opportunities and knowledge tacitness on inter-firm network formation, under two different industry regimes. In the first regime environment is stable and the aim of firms is to exploit knowledge. In this case, they attribute more value to repeated interactions with geographically close firms. In the second regime, there is environmental turbulence, which increases the value of access to novel information from distant partners for exploration. The question addressed is, under these regimes how do technological opportunities and knowledge tacitness influence structure of networks? The main contribution of the paper different from previous work is that it explicitly models the effect of history between two firms on networks that form. A simulation model is carried out where firms select partners and learn from them, which further shapes their selection process. The results reveal that in both regimes richer technological opportunities and higher tacitness generates local and global star firms depending on the parameter range.

## 1   Introduction

It is now acknowledged that networks have a significant role in shaping economic outcomes. In the economics literature, one of the areas in which network studies have received recent attention is an inter-firm network, with the recognition that external collaborations of a firm are a vital component underlying competitive advantage. The position of a firm in a network has an effect on firm performance (Mc Evily and Zaheer 1999; Ahuja 2000; Rowley et al. 2000; Hites and Hesterly 2001; Baum et al. 2000; Baum et al. 2003) and it is also a resource for the firm (Gulati 1999). These imply

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that firms may select their partners as a strategic move to improve their network positions (Baum et al. 2003). In addition to the importance of firm positions, the overall structure of these networks have implications for the way knowledge is diffused and thus effects the innovative potential of an industry (Cowan et al. 2004; Cowan and Jonard 2003).

In the literature, one of the controversies concerning how position of a firm relates to its performance arose between social capital (Coleman 1988) versus structural holes (Burt 1992) proponents. The former argues that, taking place in dense networks composed of strong ties and embedded relations (Granovetter 1985) in which interactions are frequent, face-to-face and accompanied with thick information exchange is better for performance. As these scholars argue, networks rich in social capital are associated with trust among the parties, so that concerns for reputation mitigate possible opportunistic behavior. Also these networks facilitate transfer of tacit knowledge since a common language is developed among parties, which increases efficiency in terms of time and costs of negotiation (Uzzi 1997). On the other hand, too much embeddedness can have counter effects, like rendering the firm vulnerable to external shocks or insulating it from novel information residing elsewhere in the network (Uzzi 1997).

Inspired from Granovetter's leading arguments on the "strength of weak ties" (Granovetter 1973), proponents of structural holes argue that networks rich in social capital result in redundancy of information exchange, since the same parties interact frequently and same information circles. As they argue, for increased performance firms should fill structural holes in the network, and act as "bridges" connecting otherwise disconnected clusters of firms (Burt 1992). These weak ties are advantageous in terms of getting access to novel information from diverse sources, thus beneficial for exploration purposes and when the knowledge being transferred is more codified (Rowley et al. 2000). It is argued that especially in technologically turbulent environments, a firms' access to novel information is critical for competitive advantage. Weak ties also have the benefit of giving the firm flexibility in adapting to new circumstances (Gargiulo and Benassi 2000; Uzzi 1997). One of the disadvantages of filling structural holes is that the flow of tacit knowledge is constrained, which can

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mitigate innovative performance, as observed in the case of chemicals (Ahuja 2000).

An apparent consensus concerning the debate between structural holes and social capital views is that the type of network structure conducive to better performance depends on characteristics of the industry and knowledge (Rowley et al. 2000; Burt 1998). Firms in turbulent environments may benefit more from exploring knowledge of distant firms, while firms in more stable environments can favour forming strong links with close firms to deepen their existing knowledge (Rowley et al. 2000). Empirical research in a variety of industries reveals that firm networks share some fundamental commonalities in their structure at least in certain periods of the industry life cycle. For example, research has shown that in the beginning of an industry's life cycle knowledge is less codified and technological opportunities are greater, and these factors favor a highly clustered network structure which facilitates the flow of tacit knowledge (Cowan et al. 2004; Audretsch and Feldman 1996). According to other research, firms networks are denser in periods of turbulence (Rosenkopf and Tushman 1998). But the question remains that in the beginning of the industry life cycle knowledge is tacit, yet there is also high levels of turbulance, which may favor forming links with distant partners, and have weak ties in addition to strong ties.

In general this paper addresses these issues by looking at different network structures that emerge under different industrial environments, through an agent based simulation study. In defining the environment, we focus on tacitness of knowledge and technological opportunities under two industry regimes; in one the environment is stable, and in the other there is high technological turbulence. As different from previous work, we look at the effect of history and geographical distance between firms when they decide to form links. To summarize, the central question of this paper is, if history of two firms and the distance between them matters for the benefits that a firm gains, how will the resulting networks look like under different regimes of the industry?

The paper is organized as follows. In the second section, we explain the model. In the third section we present simulation results, followed by some discussions in section four and finally concluding remarks.

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# 2 The Model

The aim of the model is to highlight the characteristics of networks that emerge when firms voluntarily select partners, under different regimes of the industry. There are two stages of this process; selection of partners and diffusion of knowledge.

## 2.1 Selection of Partners

In the first stage of the model, firms select partners by assigning an expected value to a potential partnership. This expected value depends on the industry regime and the perceived level of the partner's knowledge level. Mathematically, when ego firm $i$ is choosing among partners, he assigns the following value to a partnership with firm $j$;

$$v_{ij} = k_j(1 + \beta_{ij})\mathbf{s}_{ij}(\mathbf{h}_{ij}, \mathbf{d}_{ij}) \tag{1}$$

where

$$\mathbf{s}_{ij}(\mathbf{h}_{ij}, \mathbf{d}_{ij}) = \frac{1}{1 + e^{\alpha h_{ij}/d_{ij}}}$$

$v_{ij}$ is the value of collaboration between firm $i$ and $j$, $k_j$ is the knowledge level of firm $j$, $\beta_{ij}$ is to account for the error term that firm $i$ might commit in forming its expectation regarding the value of its collaboration with firm $j$, $h_{ij}$ is the number of times firm $i$ and $j$ has collaborated in the past, $d_{ij}$ is the geographical distance between firms $i$ and $j$, and $\alpha$ is a parameter that we vary to control for the industry regime. According to Eq. 1, the higher is the value of firm $j$'s knowledge, the more value firm $i$ places on their collaboration.

We distinguish between two industrial regimes as an *exploitation regime* and an *exploration regime* as represented in Figure 1, which shows function $s(.,.)$. The vertical axis shows the perceived value of a collaboration for the ego firm, with potential partner. Horizontal axis shows the *status* of the relationship between ego firm and the partner, which is given by number of past meetings between ego firm $i$ and firm $j$, divided by distance between them.

Values of $\alpha < 0$ represent an exploitation regime in which knowledge is highly tacit. In particular, for $\alpha < 0$, as the number of past collaborations increase between firms $i$ and $j$ and as distance between them reduces, the perceived value of a collaboration increases following a logistic curve. In this way, we capture not only the importance of previous contacts but also the geographical distance. Because knowledge is tacit, we model this relationship as a logistic curve, where the value of collaboration with a specific partner as perceived by the ego firm first increases at an increasing rate, but after sufficient meetings, the marginal contribution of the collaboration falls (i.e. the firms get to know each other sufficiently well so that there is less to be gained from each collaboration). Only when the marginal contribution of collaboration is zero, firms achieve the full benefits from collaboration. Two features of this function are important for us:

*(AS1)* Shift of the curve to the right: As the absolute value of $\alpha$ gets smaller (rightward shift of the curve) knowledge becomes more and more difficult to transfer. In other words, acquiring the same level of benefit from a collaboration requires more meetings and/or shorter distance.

*(AS2)* Change in the slope: As the absolute value of $\alpha$ gets smaller, the slope of the curve decreases. In this way the function also captures an important effect. As knowledge becomes increasingly tacit, the marginal value of status falls. For an ego firm, this means that there is very little difference in terms of expected value, of connecting to an immediate neighbour, or else the one next to the immediate neighbour, because in any case knowledge transfer is far too limited in both cases.

How sensitive is the value of a collaboration to the number of previous interactions and distance (i.e. the extent of tacitness of knowledge, $\alpha$) is a parameter we vary under this regime. In an exploitation regime, firms know that it is difficult to transfer knowledge, so they seek to build strong ties with close neighbours, and more competent firms are more attractive for a firm. Therefore, when a firm makes a decision to select a partner, she values closer partners with whom she has met more in the past, as well as who is more competent.
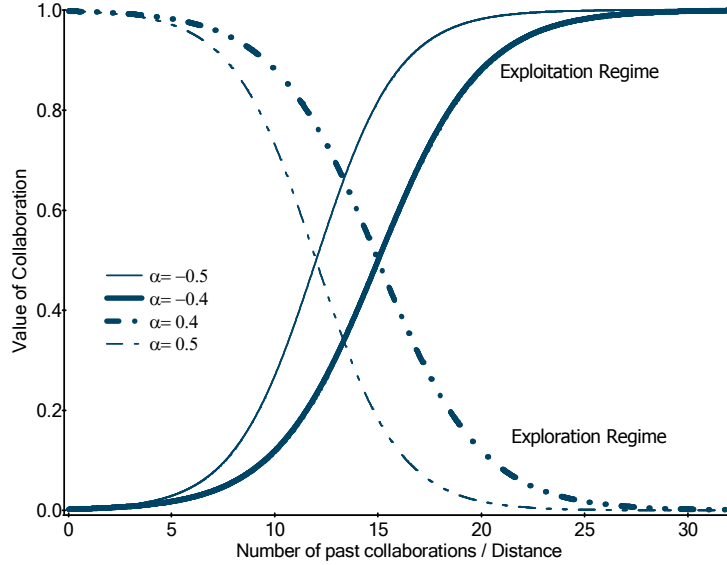
Figure 1: Exploration and Exploitation Regimes

Values of $\alpha > 0$ represent an exploration regime. Here environmental turbulence is key; more distant and novel collaborations yield more value, expected value of a collaboration falls as two partners repeatedly interact, because opportunity cost of committing resources to the same partner increases. In this case, there is no additional value to be derived from repeated interactions. On the contrary, novel partners are what firms are looking for, to access novel sources of information and to gain information about recent developments elsewhere in the network. In an exploration regime, as value of $\alpha$ falls, knowledge becomes more tacit. In other words, it requires more past meetings and/or closer distance to achieve a certain level of benefit. To summarize, the sign of alpha controls for the industry regime, while its magnitude controls for the transferability of knowledge in both regimes.

### 2.1.1 Diffusion

In the second stage of the model, every firm selects a partner by choosing the one to whom the ego firm has attributed the highest value, and collaborations form. We assume that there are no costs of establishing links, and that forming a link does not require the consent of the partner. In this way, in each period each firm collaborates

with another firm (we assume that self collaborations yield zero value), which lasts for one period. In this setting, a firm may have links with many other firms, if many other firms prefer her. In this process, firms learn from their partners and knowledge diffuses.

The extent of learning depends on the industry regime and also the range of technological opportunities in the industry. Here it is assumed that when firms are making their decisions, they have an estimation of the partner's knowledge level (given above in Eq. 1), but they are not farsighted enough to estimate what they can learn from their partners, given the combination of their own knowledge and the partner's knowledge.

In an exploitation regime, the more two firms have met in the past and the closer they are, the more they can learn from each other. On the other hand, in an exploration regime, the less they have met in the past and the more distant they are, the more they can learn from each other. In addition, industries with higher technological opportunities yield more learning.

At the end of one period, firm $i$ learns from the collaboration with firm $j$ according to

$$k_{i,t+1} = k_{i,t} \left[ 1 + \mathbf{s}(h_{ijt}, d_{ijt}) \mathbf{g}\left(k_{it}, k_{jt}\right) \right] \tag{2}$$

where we define $g\left(\cdot, \cdot\right)$ as

$$g\left(k_{i,t}, k_{j,t}\right) = \max\left\{ 0; r_{i,j}^{\gamma}\left(1 - r_{i,j}^{\gamma}\right) \right\}$$

with

$$r_{i,j} = \frac{k_{i,t}}{k_{j,t}} \tag{3}$$

where $s_{ij}$ is as explained in Eq. 1. Eq. 2 tells that, the extent of learning depends on a) history and distance and as revealed by function $s(.,.)$ and b) technological opportunities. Technological opportunities are measured by parameter $\gamma$. According to function $g(.,.)$ learning in a collaboration depends on relative knowledge levels between firms $i$ and $j$. In modelling increases in a firm's knowledge as a result of receipt of new information (See Cowan et al., 2004 for this type of learning function):

$(AD1)$ the resultant knowledge level is continuous in the initial level of the ego firm;

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($AD2$) if the ego firm knows more than the partner, the knowledge level of the ego firm does not change

($AD3$) when the ego firm's knowledge level is small relative to that of the partner, the increment to her knowledge decreases as she falls further behind;

($AD4$) it is in general possible for an ego firm to leapfrog the partner, achieving a higher knowledge level than the partner after the collaboration.

Parameter $\gamma$ measures two aspects of learning: absorption and innovation. In Figure 2 (a) and (b), the horizontal axis shows the relative knowledge levels of the ego firm i and partner j before collaboration, and the vertical axis shows the relative knowledge levels after collaboration. Here, the 45° line to the right of $r_{ij} = 1$ reveals that it is only possible to learn from more advanced people. If firm $i$ has more knowledge than firm $j$, $r_{ij} > 1$ and firm $i$'s knowledge does not change. When $\gamma = 1$, there is only absorption shown by the vertical lines. In Figure 2 (b), there is both absorption and new knowledge creation (i.e. leapfrogging). When the relative knowledge levels before collaboration are above the critical threshold $r_c$ ($1 > r_{ij} > r_c$), the less knowledgeable firm $i$ increases his knowledge over and above that of firm $j$ in the next period. This area is revealed by the horizantal lines, where the new relative knowledge levels are bigger than one. The horizontal lines show the areas of innovation. As $\gamma$ increases further, the possibilities for innovation increase. Therefore in this model $\gamma$ measures the potential of the industry to innovate (Cowan et al., 2004).

One of the distinguishing features of this model from previous work is that we take into account not only technological opportunities, but also the history of a partnership as a determinant of learning and networks. The history of a partnership is included in Eq. 2 as function $s(.,.)$ as explained in the selection process.

The reasoning behind the learning function Eq. 2 is as follows. Let us think of an industry in which technological opportunities are very high. This implies that when two firms meet, for $\gamma > 1$, the firm who knows less has even the chance to leapfrog the partner as implied by function $g(.,.)$. However, if it is an exploitation regime where knowledge is highly tacit, its diffusion between two firms will be more constrained than a regime in which knowledge is more codified (i.e. $\alpha < 0$ and lower
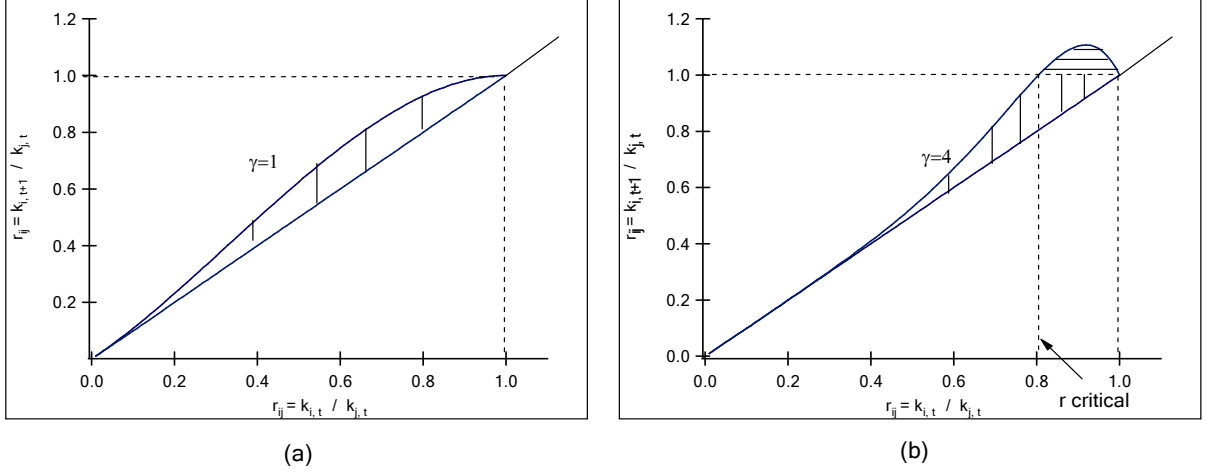
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Figure 2: Absorption and Innovation

absolute values of $\alpha$). Therefore, tacitness is a factor which inhibits the ego firm from fully utilizing technological opportunities, unless it has met with the partner firm sufficiently before. This is how the history of meetings matter. As implied by function $s(.,.)$ in Eq. 2 the more two firms have met in the past, the more chances they will have to fully utilize technological opportunities by counterfeiting the negative effect of tacitness of knowledge transfer. When knowledge is relatively more codified, these problems are of no concern. In this case history matters less for utilization of technological opportunities since its transfer is relatively easier. This function captures these aspects of the knowledge diffusion process. In short, it tells that the more tacit knowledge is, the more important it is that two firms have met more in the past (or be closer to each other geographically) to be able to capture a certain amount of technological opportunities.

These effects are shown in Fig. 3. The initial knowledge proportion is 0.9. Higher technological opportunities (square markers) yield higher knowledge creation. But if knowledge is highly tacit (filled squares) making the most of opportunities requires more meetings in the past and/or shorter distance between partners. The same is valid for low technological opportunities, which yield less chances for knowledge creation (triangle markers).

Once diffusion occurs, knowledge levels of firms are updated, and in the next
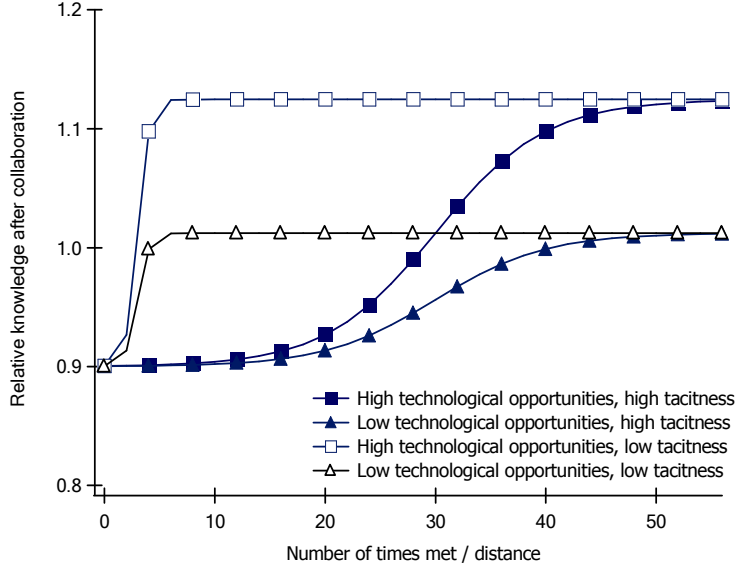
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Figure 3: Relative Knowledge Levels under different levels of Technological Opportunities and Tacitness

period, selection process is repeated. We look into the types of networks that emerge and the distribution of knowledge among firms, in the parameter space defined by technological opportunities, type of regime (i.e. exploration or exploitation) and the tacitness of knowledge.

# 3   Results

The population consists of $N = 30$ firms, who are located on a circle. Each firm $i$ is endowed with a knowledge scalar, $\mathbf{k}^i$ assigned randomly (drawn from a uniform distribution) at period $t = 0$; $k_i$ shows the level of firm $i$'s knowledge. Firms are endowed with different knowledge levels. The main parameters that we vary are $\alpha$, which measures a) the industry regime ($\alpha < 0$ for exploitation regime and $\alpha > 0$ for exploration regime), and b) tacitness of knowledge (higher values connote higher tacitness) and $\gamma$ which measures technological opportunities. In the simulations $\alpha \in [-2, 2]$, $\beta = 1 \pm 0.1$, $\gamma \in [1, 7]$. We look at measures of network structure under the parameter space defined by $\alpha$ and $\gamma$. One simulation run consists of 1000 periods. At the end of the 1000 runs, we record frequency matrices, showing the number of

times firms have formed links. We run 10 simulations for each of the parameter combinations, and the results correspond to the average of network measures.We analyse the resulting networks using social network analysis tools. In particular, we look at the degree of localization of links, reachability among firms and centrality of the networks.

## 3.1   Spatial Strength

Firstly, we measure the extent to which firms in the network form strong ties. As we use the term, strength of a tie has two dimensions; firstly it measures the extent to which the tie is constructed with a geographically close firm, and second the number of times the tie is repeated between two firms. For this purpose, the spatial strength index measures the extent to which they interact frequently with close neighbours. This is given by;

$$\frac{\sum_i \sum_j f_{ij}/d_{ij}}{N}$$

where $d_{ij}$ is the distance between firms $i$ and $j$, and $f_{ij}$ is the number of times $i$ and $j$ have collaborated. The average is taken over all firms in the population. Higher values of the spatial strength index reflect the tendency in the population to form strong ties with close firms. Lower values of the index reflect a tendency to form weak ties with distant firms. Figure 4 shows this measure.

In an exploitation regime, firms learn more by forming strong ties with close neighbours. Therefore, the absolute values of the spatial strength index is high compared to the exploration regime, in which networks are more dense and ties more diversified. In an exploitation regime, choosing a close neighbour and forming a link repeatedly enables a firm to utilize more technological opportunities that he can get from this partnership. But as knowledge tacitness increases, the spatial strength index falls. Indeed, this result is a consequence of AS2. The results are further discussed below in relation to other network measures.

An important aspect of the model is that forming a tie does not require the consent of the partner. Any firm can form a link with any other firm. Therefore this aspect
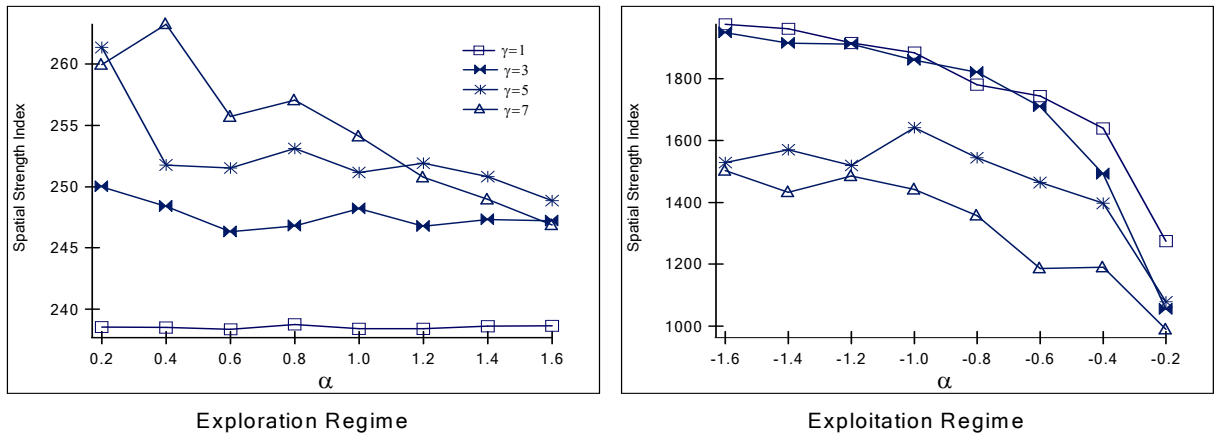
Figure 4: Spatial Strength Index

of the model permits cases in which some firms might be high in demand, which will increase the centrality in the network.

## 3.2   Centrality

Degree centrality in a network is measured as follows;

$$\frac{\sum_i c_{\max} - c_i}{(N-1)(N-2)}$$

where $c_{\max}$ is the degree of the firm with the highest connections, $c_i$ is the degrees of actor $i$.The term in the denominator gives the maximum possible value of difference among all actors (Wasserman and Faust, 1994).

Figure 5 shows that in both regimes, centrality increases with tacitness. At the same time, in industries with higher technological opportunities, centrality of the networks are higher. In the exploitation regime, it was observed that when technological opportunities are higher and knowledge more codified, there are local stars, which is evident from high spatial strength accompanied by high centralization. As knowledge becomes more tacit, these local stars are replaced by global stars, as evidenced by even higher degree centrality of the networks. To see the extent to which the firms are connected to each other, we also looked at the reachability of firms in the network.
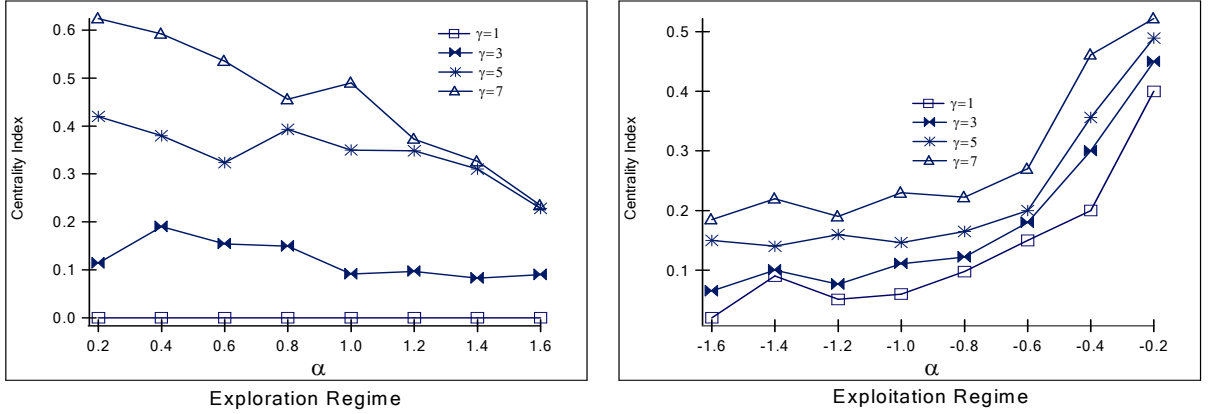
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Figure 5: Degree Centrality of the Networks

## 3.3 Reachability

Reachability of the network measures the extent to which two nodes are accessible to each other directly or via intermediaries. [1] For higher technological opportunities and codified knowledge, we mentioned above that there are local stars in the network. In Figure 6 it is possible to see that in this range the reachability depends on technological opportunities. As technological opportunities rise, firms are more connected to each other, accompanied by local stars (Figure 5), and strong ties (Figure 4). In an exploration regime, it is an expected result that all firms are connected to each other since networks are denser.

# 4 Discussion

## 4.1 Exploitation Regime

In an exploitation regime, firms can learn more from a partner the more they have met before, and the less distance between them. Although this generates a magnet effect which attracts firms to repeat links with close neighbours, this magnet effect diminishes because of two reasons: increasing tacitness, and increase technological opportunities. These are observed in Figure 4 where spatial strength index falls as

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[1]To calculate reachability in the network, the software UCINET was used (Borgatti et. al., 2002).
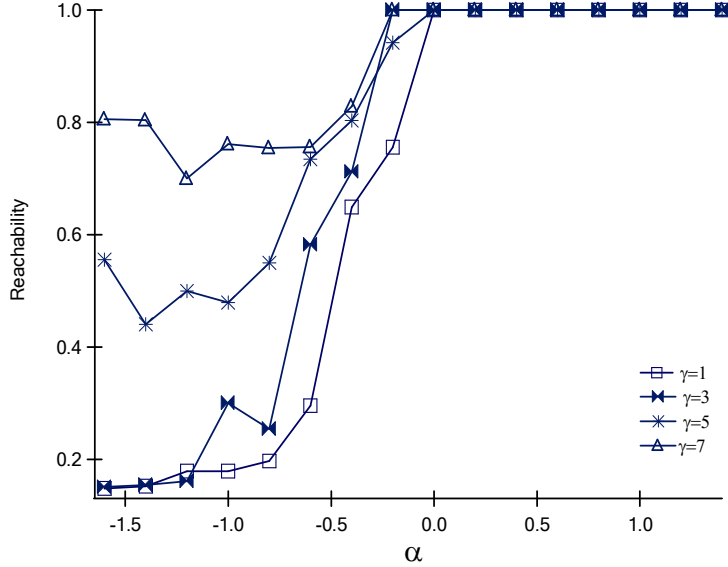
Figure 6: Average Reachability among Network Members

technological opportunities and tacitness increase.

The loosening of local interactions when knowledge is more tacit might seem contradictory to most empirical evidence, which reveals that tacitness of the knowledge base increases clustering. However, this result is hardly surprising in this model, because it is imposed by the functional form employed. This is a consequence of AS2, which states that the difference between connecting to an immediate neighbour, or else connecting to a firm in the vicinity is lower as tacitness increases. As expected, this creates a loosening of the connections towards more distant partners, which reduces strength of ties.

At the same time, it is observed that this localization is loosened when technological opportunities are higher. Moreover, an interesting effect of technological opportunities on network structure is that when knowledge is codified, higher technological opportunities generate "local stars", whereas as knowledge becomes more tacit, higher technological opportunities generate "global" stars. This can be explained by the two forces operating in opposite directions as explained below.

When an ego firm is making a decision to select partners, he can take into account the partner's knowledge level, and also their history and distance (see Eq. 1). The

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network structure that emerges is a result of the effect that dominates. If knowledge effect dominates, firms care less about their history and distance, but more about the knowledge of the partner and we see loosening of localization. For example, when knowledge of the potential partner is too high, he becomes too attractive to be ignored for the ego firm, so instead of commitment to making strong ties with close firms, he can select the star firm. If history effect dominates, firms care more about forming strong ties with close neighbours, regardless of their knowledge level. The process works in the following way.

When knowledge is codified, it is obvious that the history effect is more dominant (by axiom AS2), so firms have a tendency to form strong ties with close partners. Here, as technological opportunities increase firms have more chances to leapfrog the knowledge of their partners, provided that their relative knowledge levels are close (see Eq. 2). In this case, some lucky firms have neighbours whose knowledge levels are close to themselves. These firms can easily leapfrog their partners, and they have more chances to innovate. As this process takes place, they become more attractive for the other firms in the vicinity. In other words, having a firm in the vicinity whose knowledge becomes significantly higher than others attracts other firms to the star firm. For these peripheral firms, this is the case where the knowledge effect starts dominating the history effect, because there is a firm in the vicinity whose knowledge is too big to ignore. Because transfer of knowledge is easier when knowledge is codified, the knowledge gap between peripheral firms and the star firm does not grow too much. Therefore star firms always remain as the local stars, without being able to extend their field of attraction to all the network. This is why the centrality is higher for higher technological opportunities in Figure 5, which also corresponds to the region where spatial strength is high. In this way, the spatial strength because of less tacit knowledge, and the loosening effect because of higher technological opportunities yield the emergence of local stars.

As knowledge becomes more and more tacit, axiom AS2 tells that spatial strength will be lower in the network as explained above. In this case, the knowledge effect can dominate the history effect. Therefore firms will have a tendency to prefer knowledgable partners to forming strong ties with close neighbours. However, in this
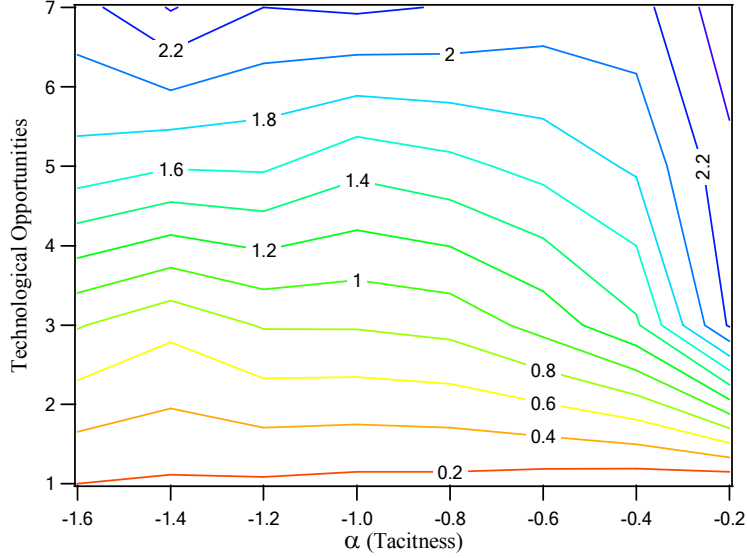
Figure 7: Diversity of knowledge levels (standard deviation of knowledge)

case knowledge is relatively more difficult to transfer. Some lucky firms who have neighbours with similar knowledge levels in the vicinity start innovating. This time, however, because it is relatively difficult to transfer knowledge, the gap between these firms and peripheral firms keeps increasing and peripheral firms fall further behind (see axiom AD3). This is how some firms become more and more attractive, and extend their field of attraction to other firms in the network, and eventually they become "global" stars.

To confirm these results, we also looked at the knowledge gap among firms, measured by the standard deviation of knowledge in the population. Figure 7 gives this measure. As it can be seen, both technological opportunities and tacitness of knowledge have the effect of increasing the knowledge gap among firms.

## 4.2    Exploration Regime

In an exploration regime, firms want to meet new and distant firms to be informed about knowledge residing elsewhere in the network other than in close vicinity. The results reveal that in an exploration regime, the same rules hold as for the exploitation regime. More specifically, higher technological opportunities and knowledge tacitness

increase centrality (Figure 5). The main difference between the exploration and exploitation regimes in terms of networks is that, in the former case networks are denser, and thus spatial strength index is lower (Figure 4). Figure 6 shows that in an exploration regime, all nodes are reachable from each other as a result.

To interpret these results, let us think of the two forces at work in partner selection; knowledge of the partner and history of interactions. Contrary to the exploitation case, here the dilemma that a firm faces is whether to connect weakly to a distant firm and have access to novelty, or to connect to highly competent firms. Because there are no increasing returns from repeated interactions, firms can now select both options. This is why the spatial strength index is very low, and the reachability of the network is 1 in an exploration regime. In short, the networks are very dense, as expected.

One interesting result in this regime is that when technological opportunities are high, network centrality is higher. There are some firms who benefit from their distant connections more than other firms because of relative knowledge levels. This gives them more chances to innovate. In this way, they become more attractive to other members of the network. When knowledge is codified, its transfer is easier, so overall knowledge differences among the firms do not grow too much. As knowledge gets more and more tacit, star firms strengthen their position in the network, because their knowledge easily exceeds that of other firms. In other words, only these firms can make use of technological opportunities in the industry while others are attracted to them without being able to learn too much and by falling further behind (see axiom AD3). In this way, higher tacitness and technological opportunities generate stars in the industry as revealed by higher centrality measures in Figure 5.

# 5    Conclusion

In general, simulation models enable a wide range of experimentation possibilities despite their abstractness. In this sense, this paper is not an exception. The simulation model in this paper reveals some interesting dynamics related to emerging network structures under different industry regimes. One important contribution of this paper is that, it not only looks at the effect of different industry regimes, but

also explicitly takes into account the effect of history and distance between two firms on learning and networks.

According to the results of the paper in a world where we can distinguish between two regimes as an exploitation regime and an exploration regime, different network structures emerge depending on technological opportunities and extent of transferability of knowledge. In an exploitation regime, value of a collaboration and learning increases as firms meet more with each other and with those who are close to themselves. Here we assume that the environment is rather stable. On the other hand, in an exploration regime, the environment is turbulent, so opportunity cost of committing to a single close firm is higher, in terms of foregone access to novel information residing elsewhere in the network. In this case, firms do not want to interact repeatedly, rather they search for novel and distant partners.

In an exploitation regime, networks are composed more of strong ties, where firms interact repeatedly with geographically close firms. In this regime, high technological opportunities and tacitness result in the emergence of local and global stars in the network respectively, who are more competent than other firms. Our results imply that in an exploitation regime, firms who are similar to each other in terms of their knowledge level should be in the same vicinity to capture the most of technological opportunities. When knowledge is highly tacit, too much diversity in knowledge reduces the chances to capture technological opportunities, and increases the knowledge gap among actors, producing local and global star firms.

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