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INFORMATION-DRIVEN CLUSTERING: AN ALTERNATIVE TO THE KNOWLEDGE SPILLOVER STORY

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Information-driven Clustering – An Alternative to the Knowledge Spillover Story

Abstract: This paper builds a model in which clustering emerges as the equilibrium outcome driven by informational imperfections and the importance of knowledge and uncertainty in innovative production even when knowledge is fully exclusive and appropriable. This motive for clustering will be stronger the more important new knowledge in the industry. It thereby helps to account for the empirical finding that economic activity clusters more strongly in industries where new knowledge plays a bigger role. It weakens the case for local knowledge spillovers to explain innovative clustering.
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1 Introduction

The notion of knowledge spillovers has taken a prominent role in attempts to explain clustering of economic activity. At the same time the presence of agglomerations has been one of the main justifications for the presence of spillovers. The circularity of this argument has been pointed out in different places in the literature (KRUGMAN, 1995, p. 639). Previous studies have also criticised knowledge spillovers as a “black box” phenomenon (e.g., BRESCHI & LISSONI, 2001) because several detailed studies of knowledge flows reveal markets at work instead (e.g., ZUCKER, DARBY, & ARMSTRONG, 1998).

In a paper published in the American Economic Review, AUDRETSCH & FELDMAN (1996) establish for the US that empirically the propensity of economic activity to cluster is higher the more important a role new knowledge plays in an industry. This finding is in line with previous work for instance by HILPERT (1992) on the location of innovative activity in Europe. AUDRETSCH & FELDMAN (1996, p. 630) use their finding to link “geographic concentration to the existence of knowledge externalities" and interpret their result as evidence in favour of the existence of local knowledge spillovers.

This paper takes as a stylised fact and offers an alternative explanation for the stronger clustering of more innovative activity. I point out that Audretsch and Feldman's interpretation is highly sensitive to an assumption with regard to the costs of information transmission, namely that the cost of transmitting information be invariant to distance (AUDRETSCH & FELDMAN, 1996, p. 630). With costs of transmitting information about new knowledge increasing in distance, however, clustering emerges as the equilibrium location choice of profit maximising firms. This result is driven by informational imperfections and the importance of complementarity and uncertainty inherent to innovative activity, even without knowledge spillovers. The observation of stronger clustering of more innovative activity therefore is consistent with the absence of any knowledge externalities if the cost of evaluating information about new knowledge is rising in distance (see Figure 1). This further weakens the case for knowledge spillovers in economic theory and policy.

2 Motivation, Argument and Literature

2.1 Motivation

AUDRETSCH & FELDMAN (1996) find for the US that industries in which new knowledge is more important have a greater propensity for innovative activity to cluster even after controlling for the concentration of production in the industry. They use Gini-coefficients based on four-digit SIC level innovation (output) counts of the US Small Business Administration at the state-level weighted by the national innovation count for the industry to measure the concentration of innovative activity. Following ARROW (1962) and KRUGMAN (1991) they use industry R&D intensity, or R&D-sales ratios, to measure the importance of new economic knowledge in an industry. Using the share of skilled labour in industry employment and the expenditure on university research for relevant departments as further measures for the degree of innovativeness of an industry, they frame the interpretation of their findings solely in terms of the importance of knowledge spillovers by concluding that "Even after controlling for the concentration of production we find evidence that industries in which knowledge spillovers are more prevalent [...] have a greater propensity for innovative activity to cluster than industries where knowledge externalities are less important." (AUDRETSCH & FELDMAN, 1996, p. 639)

2.2 Argument

(1) The importance of complementarity and non-predictabilit in innovative activity leads to a gap in the potential economic value of new knowledge and the effective value, i.e. the economic value realisable by a specific agent, if it is less than fully complementary with the agent's existing knowledge (SIEVERS, 2005).

Consider a firm which has come across new knowledge in period one. This company will then gear its organisation towards exploiting the value of this new knowledge. Think of one period to represent the time of an innovative product life-cycle and assume that the firm will appropriate the whole economic value of an invention in the period of its discovery, and that afterwards this knowledge becomes public. Now consider the next period. The company has inherited an organisational structure, human capital, a sales apparatus, client relationships and a brand from last period which were geared towards exploiting last period's new knowledge which by now has been fully appropriated. I treat the direction of last period's knowledge vector as a measure for the orientation of the company's existing organisation, routines, skills and assets. The aim of the innovative firm in period 2 is again to produce and exploit new knowledge. Its organisational inheritance, however, will make it more difficult for the firm to exploit the full economic potential of the new knowledge the less complementary this knowledge is to period 1's knowledge.

Merging this idea with the inherent lack of predictability in R&D output and hence control in knowledge production over the complementarity of new knowledge with existing knowledge, there is scope for increasing efficiency through the reallocation of new knowledge to firms with more complementary existing knowledge. Hence, to the extent that existing knowledge from previous periods is a proxy of the amount of a company's past activity and organisation for and conventions of doing business, it will be more difficult to extract the full revenue potential from new knowledge the more old knowledge a company has.

(2) Firms trade knowledge in a market to exploit profit opportunities from reallocation of new knowledge.

Let new knowledge be fully exclusive and appropriable. Consider an innovative firm which produces a new knowledge vector of less than perfect complementarity with its existing knowledge vector. If this new knowledge vector is more complementary to the existing knowledge vector of another firm it might be profitable for the latter firm to buy the new knowledge of the former firm at a price that fully compensates the producer of the new knowledge for his own profits forgone. It can be shown for the setup of this model that – as would be expected – the profit-maximising firm prefers more information to less as the basis for its trades on the knowledge market.

(3) To the extent that it improves the information structure for the reallocation of new knowledge clustering becomes the dominant strategy for profit-maximising firms.

I distinguish between knowledge and information about knowledge. Let knowledge be fully exclusive for its owner in the period of its invention and public afterwards, and let information about knowledge be freely available.[1] Also assume that there are costs of processing and using the freely available information about knowledge of each firm and that these are increasing in the distance from the source. It is beneficial for firms to have more information about other firms' new knowledge vectors when engaging in knowledge trades and I take the expected marginal benefit from one extra information signal to be positive and invariant with distance. Under these assumptions clustering is the optimal strategy for each firm's location choice: Costs from the evaluation of information are minimised and information benefits are maximised if a maximum number of senders and receivers of information are at a minimum distance to each other. There is

[1] The assumption to treat knowledge as public from the period after its invention onwards can be seen as an extreme case of knowledge diffusion or "spillover" of unprotectable knowledge.

an infinity of Nash equilibria which consists of one or several clusters at different points in space.

Due to the fact that the characteristics that give rise to this motive for clustering are contingent on the importance of complementarity and the lack of predictability of output inherent in innovative activity, this approach provides a potential explanation for the empirical finding that innovative activity tends to cluster more strongly than non-innovative activity.

2.3 Literature and Context

The existing literature on clustering of economic activity can be broadly divided into three main categories (e.g., MALMBERG & MASKELL, 2002):

1. Genealogical approaches with a focus on historical origins and evolution
2. Approaches of cost reductions through clustering by way of exploiting localisation economies
3. Local knowledge spillover arguments

This paper proposes a further motive for clustering resulting from the specific characteristics of knowledge in economic activity and informational imperfections. It therefore is of particular relevance to explain clustering of innovative activity because here new knowledge is particularly important.

The approach in this paper departs from the existing literature dealing with innovative activity in five main ways: Firstly, building on SIEVERS (2005) the paper explicitly takes into account the peculiarities of knowledge in economic activity, namely its cumulativeness and the importance of complementarity, innovation rents and uncertainty. The literature has so far approached knowledge in an one-dimensional way, like a variable which can take a uni-dimensional value. To reflect the special nature of knowledge I model it as a vector characterised by a length, which reflects its potential economic value, and a direction, which models the complementarity of knowledge with other knowledge. This allows to model knowledge in economic activity without excessively distorting its special characteristics.

Secondly, I assume knowledge to be perfectly excludable. This view offers an alternative to the reliance of the current literature on local knowledge spillovers as the main driver of clustering. The latter, widely accepted approach adopts a distinction between tacit and explicit knowledge (e.g., COWAN & FORAY, 1997). It is then assumed that tacit knowledge does not spread easily from one location to another because unlike explicit knowledge it is hard to codify. Within a cluster, however, tacit knowledge is taken to spill over from one firm to another. A typical spill-over situation would for instance be a social contact of the employees of different firms or the exchange of employees through the labour market. A problem with the literature so far is that very few papers have attempted to spell out the precise channels and mechanisms involved in the spill-over process,[2] leading to the criticism of local knowledge spillovers being a "black box" for things the researcher had otherwise not been able to capture (e.g., BRESCHI & LISSONI, 2001). In this study I argue that the spillover approach to knowledge diffusion is inappropriate for the kind of new knowledge that drives growth in advanced economies. Such knowledge is often complex, cumulative and dependent on its context and complementarity with specific other knowledge. Therefore, it should not be expected to spill over between firms for the same reasons it does not spill over between locations: The effort and time involved in transferring it are too large. Given perfect excludability, new knowledge is traded in a market instead and hence appropriable for its inventor.

Thirdly, with regard to the information structure the current literature treats information as well as explicit knowledge as easily codifiable messages which are available costlessly or at low cost invariant to distance. While this probably is a correct description of the supply side of information, I argue that due to search and processing costs of gathering and evaluating information for the receiver, it is useful to analyse information imperfections, at least for information about new

[2] An example for an empirical paper that attempts to trace out the exact mechanism of the knowledge transfer is ZUCKER, DARBY & ARMSTRONG (1998), who use data on the Californian biotechnology industry and come to the conclusion that knowledge is not transferred via spillovers but through market exchanges between star scientists and biotechnology companies.

knowledge. This is particularly relevant in a situation of information overload, in which the receiver has to find, verify and interpret information that is relevant for him. An important point in this context is the distinction between knowledge and information about knowledge.

Fourthly, in the view proposed in this paper clustering helps eliminate informational imperfections, thereby eliminating a source of market failure and providing an incentive for innovative firms to cluster. This point differs subtly but significantly from previous contributions in the literature which introduced the idea that clusters help mitigate the risks – or what DOSI (1988) called "uncertainty"[3] – inherent in innovative activity (FELDMAN, 1994a, 1994b). This is equivalent to a claim that clustering somehow changes the knowledge production technology, for instance by skewing the probability distribution of the realisation of new knowledge's complementarity with the firm's existing knowledge in a favourable way. Such an assumption is not necessary for clustering in this paper.

Finally, the paper aims to address a problem of circular causation in existing theoretical studies on local knowledge spillovers (KRUGMAN, 1995; MALMBERG & MASKELL, 2002). While the exact spillover mechanism leading to the alleged benefits of clustering are not clearly identified, those studies turn the chain of reasoning on its head and use the observation of clustering as proof of the existence of the "black box" of knowledge spillovers. I develop a model of how knowledge is transferred between profitmaximising firms first and then show how a cluster emerges contingent on assumptions on the information structure as a consequence of profit-maximising firms' behaviour. Therefore, this paper does not commit the fallacy of reverse causality.

3 Model

I use the methodology set out in SIEVERS (2005) to represent knowledge as vectors characterised by a length, which reflects its potential value, and a relative

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[3] The first of DOSI's (1988) so called "stylised facts" of "contemporary innovation".

direction, which models the complementarity of the knowledge with other knowledge. The potential value of a knowledge vector and its complementarity with the existing knowledge of its owner then determine its effective value. This allows to model knowledge without compromising its inherent nature in economic activity, in particular characteristics such as cumulativeness and the importance of complementarity, innovation rents and uncertainty.

3.1 The Innovative Firm

I define an innovative firm as an organisation that produces and sells innovative products. Products are innovative if they are produced with the input of new knowledge and are modelled as the output of a production process of producing or otherwise acquiring new knowledge. To define the meaning of the word "innovative" the paper follows the concept of Schumpeter of a broad understanding of innovation comprising not only new goods and services but also any novel contributions to redesigning or otherwise improving existing products and processes or accessing new markets (SCHUMPETER, 1934). For the definition of the term "knowledge", however, we adopt a more narrow concept. The type of knowledge for which the analytical approach of this paper is most relevant – particularly in the light of later assumptions with regard to the information structure and excludability of knowledge – is complex knowledge in industries like for instance IT, biotechnology, arms, and high-tech industrial production. The distinction between knowledge and information is of particular importance and has been used in other work. Knowledge in this paper is treated as an asset, which can be owned, used and sold. It enables its owner to do something which would not have been possible without having this knowledge, like producing a certain product, or improving its quality, management or production process. In particular, knowledge is not the same as information about knowledge, and to this extent the concept of knowledge in this paper is close to the notion of "tacit" as opposed to "codified" knowledge as used elsewhere in the literature (e.g., NELSON, 1990; PAVITT, 1987; ROSENBERG, 1990). For a firm to have information about the direction and potential economic value of another firm's new knowledge does not imply that it can make use of this new knowledge. This corresponds to the spirit of the distinction employed by AUDRETSCH & FELDMAN (1996) but deviates from the definition of DASGUPTA & DAVID (1994) who treat information basically as knowledge packaged for transportation.

I assume that all knowledge becomes public after the period of its invention. It follows that each firm knows the length and direction of all other firms' total knowledge vectors of the previous period. Consequently, the information needed to fully characterise a firm in each period is the length and direction of its new knowledge vector of that period. I shall use $s\left(\|\vec{n}_t^i\|, \alpha(k_{t-1}^j, \vec{n}_t^i)\right)$ to denote the information about firm *i* which is assumed to be available costlessly to each firm *j*. Hence, a firm can be fully described by the length, the direction and the signal describing its vector of new knowledge (See Figure 2). For the remainder of this paper I will use to denote the information signal about *j* available to *i*, $s\left(\|\vec{n}_t^i\|, \alpha(k_{t-1}^j, \vec{n}_t^i)\right)$ and *A* to denote the set of all firms. *A* is taken as exogenously given for the remainder of this paper.

3.2 Knowledge Production and Accumulation

Let $f_i^t\colon \mathbb{R} \to \mathbb{R} \times (0°, 360°)$ be the knowledge production technology for *i*'s vector of new knowledge in period *t*, $\vec{n}_t^i$, such that

$$f_t^i\colon e_t^i \to \|\vec{n}_t^i\|, \beta(\vec{n}_t^i) \tag{1}$$

where e_t^i is a scalar denoting *i*'s R&D expenditure in period *t*. $\|\vec{n}_t^i\|$ is the length of $\vec{n}_t^i$ calculated as its Euclidean norm and is a known function $g_t^i\colon \mathbb{R} \to \mathbb{R}$ of e_t^i,

$$\|\vec{n}_t^i\| = g_t^i(e_t^i) \tag{2}$$

with $g_t^{i\prime} > 0$, $g_t^{i\prime\prime} > 0$. $\beta(\vec{n}_t^i) \in (0°, 360°)$ is a random variable following a known probability distribution and denotes the direction of the new knowledge vector. The interpretation of the scalar $\|\vec{n}_t^i\|$ is that it denotes the length and hence the potential value of $\vec{n}_t^i$, while $\beta(\vec{n}_t^i)$ is the basis for evaluating the relative direction and hence complementarity of $\vec{n}_t^i$. This allows to operationalise the notion of uncertainty in innovative activity. A firm can plan the amount of knowledge it produces with certainty, but it cannot predict with certainty what kind of new knowledge it will produce.

Knowledge accumulation can be modeled with the help of simple vector addition. For firm *i* this can be written as

$$\vec{k}_t^i = \vec{k}_{t-1}^i + \vec{n}_i^i \tag{3}$$

where $\vec{k}_t^i$ is the total knowledge vector of firm *i* in period *t* which results from adding period *t*'s new knowledge, $\vec{n}_t^i$, to the inherited knowledge vector from the previous period, $\vec{k}_{t-1}^i$ (see Figure 3). This captures the notion of cumulativeness of knowledge as a function of complementarity as discussed above.

To the extent that knowledge is the defining asset of innovative firms one can think of $\vec{k}_{t-1}^i$ as a proxy for a firm's inherited organisation. The knowledge accumulation process above then captures notions of bureaucratic inertia (ELIASSON, 1996) and difficulties to "unlearn" knowledge of the past when it has ceased to be useful (DEMSETZ, 1988).

3.3 Innovation Rent and Complementarity

Building on the notion of an innovation rent consider the following simple payoff function

$$\Pi_t^i = \max\{(R_t^i(\vec{n}_t^i) - e_t^i), (-e_t^i)\} \tag{4}$$

$$R_t^i(\vec{n}_t^i) = h\left(\alpha(\vec{n}_t^i, \vec{k}_{t-1}^i)\right) \cdot \|\vec{n}_t^i\| \tag{5}$$

$R_t^i(\vec{n}_t^i)$ is the revenue firm *i* can realise by exploiting the new knowledge $\vec{n}_t^i$, and $\alpha(\vec{n}_t^i, \vec{k}_{t-1}^i) \in (0°, 180°)$ denotes the (smallest) difference in direction of $\vec{n}_t^i$ and $\vec{k}_{t-1}^i$.[4] h is a continuously differentiable function with $h(0) = 1$ which is monotonously decreasing in $\alpha(\vec{n}_t^i, \vec{k}_{t-1}^i)$, i.e. $h' < 0$. As an inverse index of complementar-

[4] To let the payoff from new knowledge be bounded downwards by $(-e_t^i)$ is equivalent to giving firms an option to ignore new knowledge which would be detrimental for them to pursue.

ity $\alpha(\vec{n}_t^i, \vec{k}_{t-1}^i)$ is an important determinant of how much of the potential economic value of new knowledge a firm can realise.[5]

3.4 The Market for Knowledge Reallocation

Instead of or in addition to producing new knowledge itself, a firm can acquire new knowledge by buying the new knowledge of another firm. In this case the knowledge that is bought is used by the buyer in the same way as a new knowledge vector from the buyer's own production.

In order for a firm to sell its new knowledge to another firm, two conditions have to be met:

1. The seller has to agree: An offer price *P* is accepted by the seller if and only if *P* is at least as large as the sum of the seller's expected current and discounted future profits forgone.
2. The buyer has to agree: An offer price *P* is extended by the buyer if and only if *P* is at most as large as the expected change in current and discounted future profits as a consequence of the acquisition.

The price will be determined in a bidding process. Each firm with an interest in buying firm *j*'s new knowledge vector participates in a bidding contest, which takes the following form: Starting with a very low price a neutral market maker calls out prices, which rise until both of the following conditions are met:

1. All but one firm do not wish to buy *j*'s knowledge at the current price any more.
2. Firm *j* is willing to sell at this price.

The knowledge trade will take place at the first price for which these two conditions are satisfied. Note that the buyer has no price setting power here: While the parameters of the buyer determine a ceiling for the price which it is willing to pay,

[5] There is a large variety of alternative payoff functions based on this set-up which also capture the role of complementarity and innovation rents.

the actual acquisition price depends on the parameters of the seller and the competitors for the acquisition of the new knowledge.

A firm *i* will want to buy the new knowledge of a firm *j* if the expected profit from this transaction is positive. Let Π_t^{ij} be firm *i*'s profit from acquiring firm *j*'s new knowledge in period *t*.

$$\Pi_t^{ij} = R_t^i(\vec{n}_t^i) - P_t^{ij}, \tag{6}$$

where P_t^{ij} is the non-negative acquisition price paid by firm *i* to buy firm *j*'s new knowledge vector. In the absence of perfect information each firm *i* will have to make its acquisition decisions contingent on its information set in period *t*, Ω_t^i. I assume that firms are risk-neutral. Let $E(\Pi_t^{ij})|\Omega_t^i$ denote firm *i*'s expectations of Π_t^{ij} in period *t* contingent on Ω_t^i. To simplify the notation I write $E_t^i(\Pi_t^{ij})$ instead of $E(\Pi_t^{ij})|\Omega_t^i$ from now on. For any price P_t^{ij} the condition for firm *i* to want to acquire $\vec{n}_t^j$ in period *t* is

$$P_t^{ij} < E_t^i R_t^i(\vec{n}_t^j).^6 \tag{7}$$

Similarly, firm *j* will consent to being taken over by firm *i* at any price P_t^{ij} if and only if the purchase price compensates it for its revenues forgone at the time of the acquisition.[7]

$$P_t^{ij} \geq E_t^j R_t^j(\vec{n}_t^j) \tag{8}$$

From these considerations one can derive a range for the purchase price P_t^{ij} for transactions to take place.

$$E_t^j R_t^j(\vec{n}_t^j) \leq P_t^{ij} \leq E_t^i R_t^i(\vec{n}_t^j) \tag{9}$$

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6 Note that if Ω_t^i comprises the information signals not only of firm i but also of all other firms in period t, the expectations operator can be dropped when relating to realisations of variables from the same period.

7 Note that firm *j*'s R&D expenditure is inconsequential at this stage as these are sunk costs by the time it has to make the decision to sell or not.

While equations (7) and (8) are necessary conditions for a trade to take place, they are not sufficient because another firm might have an interest in buying firm *j*'s new knowledge too. For firm *i* to win the ensuing bidding competition it must be the case that

$$E_t^i \Pi_t^{ij} \geq E_t^k \Pi_t^{kj}, \forall k \neq i \,, \tag{10}$$

The social surplus, W_t^{ij}, from a reallocation of new knowledge of firm j to firm *i* is

$$W_t^{ij} = R_t^i(\vec{n}_t^j) - R_t^j(\vec{n}_t^j) \,.[8] \tag{11}$$

The price determines the allocation of the surplus. How it will be shared between buyer and seller, will depend on supply and demand in the acquisition market: If the buyer *i* is the only firm with an interest to purchase the new knowledge of seller *j* then equation (8) will hold with equality and the whole surplus goes to the buyer. If however there are several firms with an interest in buying firm *j* then the firm for which the acquisition will realise the highest surplus will win the bidding because it can afford to bid the highest price (which will be just above the price the second highest bidder could have afforded to offer). As a consequence, P_t^{ij} will be higher and more of the surplus goes to the seller.

In summary, therefore, the importance of complementarity and uncertainty in innovative activity leads to a gap between the potential economic value of new knowledge and the effective value realizable by a specific agent with less than fully complementary existing knowledge. Reallocation of new knowledge to a firm with more complementary existing knowledge becomes a profitable opportunity. This provides a market-based framework for the analysis of channels for knowledge transfers, e.g. the M&A market, the labour market or the market for partnerships and co-operations.

[8] Note that firm *j*'s R&D expenditure is inconsequential at this stage as these are sunk costs by the time it has to make the decision to sell or not.

3.5 The Choice of the Information Set

I assume that each firm learns the complementarity and length of its own new knowledge vector immediately but only knows the information about other firms' new knowledge vector after evaluating their information signals, s_t^{ji}. The information set of firm *i* is defined as comprising the information about all other firms' new knowledge whose information signal s_t^{ji} firm *i* has evaluated,

$$\Omega_t^i = \left\{ j \in A \middle| firm..i..knows..s_t^{ji}..in..period..t \right\} \qquad (12)$$

I further assume that in principle information signals are available to all other firms regardless of their geographical location. s_t^{ji} is treated as the information signal of firm j available to every firm i regardless of its location for all other firms. However, information is costly to acquire and use (SIMON, 1955, 1959). Hence, absorbing, evaluating and processing the freely available signal is costly for the recipient. Crucially, this cost is assumed to be increasing in the geographical distance between sender and receiver. I denote the cost of firm i of evaluating s_t^{ji} as

$$c_t^{ij} = c(d_{ij}), \text{ with } c'(d_{ij}) > 0 \qquad (13)$$

with $\lim_{d_{ij}\to 0} c_t^{ij} = 0$, $\lim_{d_{ij}\to \infty} c_t^{ij} = \infty$ where d_{ij} is the distance between *i* and *j*, which introduces the notion of space into the model. One can define the total search costs for firm *i* as follows

$$C_t^i = \sum_{j \in \Omega_t^i} c_t^{ij} \qquad (14)$$

The justification for the assumption that the cost of searching, processing and evaluating a signal is increasing in distance between sender and receiver is that information about nearby companies can be assessed almost costlessly through familiarity with the neighbourhood and the social and professional contacts and networks of a firm and its employees, which are predominantly local. Also, local media make it easier to evaluate and process information signals of nearby firms. Hence, the further away the sender of information the more costly it is for the receiver to absorb and evaluate it. Given that the evaluation of information signals s_t^{ij} is costly, Ω_t^i does not necessarily comprise the information signals of all other firms in period t.

4 The Location Game

I assume that firms act to maximise profits taking the actions of all other firms as given. Figure 4 gives an illustration of the order of play. Each period consists of four stages.

1. Each firm chooses its location on a homogenous plane.
2. Based on the knowledge of its own innovative production function f_t^i each firm *i* firstly decides how much to invest into own R&D, e_t^i. Following the choice of e_t^i the new knowledge vector is realised.
3. Each firm decides how many information signals of other firms to evaluate. This determines the information set Ω_t^i of each firm which is the basis for its trades in the knowledge market.
4. Each firm then forms expectations based on Ω_t^i of the new knowledge $\vec{n}_t^i$ of all other firms and based on this engages in knowledge trades according to the conditions set out in section 3.4. Finally, all revenues are realised.

Note that the firm can engage in more than one activity in each period. The innovative firm will do all activities to the extent that they increase its expected profit. For instance, one firm can produce new knowledge, sell this new knowledge to another firm and buy several new knowledge vectors all in the same period.

Stage 4: knowledge trades

Stage 4 of the game will be played out according to the conditions set out in section 3.4. Each firm will make all trades which according to its information structure, Ω_t^i, and its own new and existing knowledge vectors, $\vec{n}_t^i$ and $\vec{k}_{t-1}^i$, are expected to be profitable.

Stage 3: information rents

In stage 3, the firm will take into account the impact of its choice of Ω_t^i on the number and profitability of its knowledge trades in stage 4. Ω_t^i is only relevant for the firm's decision of which other new knowledge vectors to buy, not for its decision of whether or not to sell the new knowledge vector from its own production.

It is possible to show that – as would be expected – a profit maximising firm prefers more information to less. The availability of information leads to efficient outcomes and can prevent allocative inefficiencies which may result from an imperfect information basis in the market for new knowledge. With perfect information, firms can use the knowledge market to reallocate new knowledge to where it generates the maximum revenue with certainty.[9]

Let J_t^i denote the set of all firms whose new knowledge *i* buys in period *t*,

$$J_t^i = \{j \in A | i..buys..\vec{n}_t^j..in..period..t\}. \quad (15)$$

Firm *i*'s total profit from all trades in period t are

$$\Pi_T^i = \sum_{\forall j \in J_t^i} \Pi_t^{ij} = \sum_{\forall j \in J_t^i} [R_t^i(\vec{n}_t^j) - P_t^{ij}]. \quad (16)$$

From the conditions for firm *i* to buy a vector of new knowledge from another firm it is clear that based on its limited information set Ω_t^i a firm might engage in knowledge trades which turn out to be unprofitable ex post, namely if $R_t^i(\vec{n}_t^j) < P_t^{ij} < E_t^i R_t^i(\vec{n}_t^j)$. Furthermore, based on its expectations a firm might decide to not offer a high enough price to acquire a vector of new knowledge which would have been profitable for it to buy at this price and hence end up missing out on profitable trades. Both these mistakes, however, will only occur with firms whose information signal the buyer chose to not evaluate. It follows that

[9] The resulting distribution of the surplus is not necessarily ex-post Pareto superior to the outcome that would have obtained under imperfect information.

$$\frac{\Delta\left[E_t \Pi_T^i\right]}{\Delta\left|\Omega_t^i\right|} > 0 \,, \tag{17}$$

i.e. the firm can earn an information rent by evaluating other firms information signals.

Stage 2: knowledge production

In stage 2, the firm will choose e_t^i in order to maximise its expected profit. If the firm chooses e_t^i independently of its actions in other stages of the game, its optimal choice will be the solution to $\max_{e_t^i} \Pi_t^i$, which is

$$e_t^{i^*} = g'^{-1}\left\{1/E_t^i\, h\left[\alpha\left(\vec{n}_t^i, \vec{k}_{t-1}^i\right)\right]\right\}^{10} \tag{18}$$

The choice of Ω_t^i is only relevant for the firm's decision of which other new knowledge vectors to buy, not for its decision of whether or not to sell the new knowledge vector from its own production to other firms. The influence of later stages on the choice of e_t^i, however, arises due to the possibility that new knowledge might yield more when sold to another firm than when used by the inventor itself. Then the more other firms there are and the wider the spectrum of directions of existing knowledge vectors, $\beta\left(\vec{k}_{t-1}^j\right), j \in A$, the higher the probability that the producing firm can realise a decent revenue from its new knowledge even in case of a realisation of $\vec{n}_t^i$ of less than expected complementarity. This would increase the optimal level of e_t^i above the level in equation (18). In the current, static version of the model I take as given both parameters, the number of firms and the distribution of $\beta\left(\vec{k}_{t-1}^j\right), j \in A$. Therefore, I can abstract from these phenomena in what follow so that the choice of e_t^i is taken independently of the firm's actions in other periods in this game.

Stage 1: location choice

From equation (17) we know that the firm's expected profit from knowledge trades is higher the larger its information set, Ω_t^i. Assume that the expected profit

[10] Assuming risk neutrality and no budget restrictions.

increase for firm *i* due to information about one further firm will be the same across all firms and can be denoted by the non-negative constant *b*. The expected total gain from all of firm *i*'s searches therefore can be written as

$$E_t^i B_t^i = \left|\Omega_t^i\right| \cdot b.^{11} \tag{19}$$

Note that B_t^i is invariant with respect to the distance between *i* and *j*. d_{ij} and the expected marginal benefit of firm *i* evaluating the signal of firm *j* is constant, $MB_{ij} = b$. It was established in section 3.5 that the marginal cost of evaluating an information signal $MC_{d_{ij}}^{search} = c_t^{ij}$ is increasing in distance of the receiver from the sender, $c'(d_{ij}) > 0$.

The profit-maximising firm will evaluate further signals as long as the expected marginal cost is equal or smaller than the expected marginal benefit of searching one extra firm. From the above discussion one can derive the following preliminary conclusions:

1. The total number of searches of each firm will be limited because the marginal benefits of search are constant while the marginal costs are increasing in distance.[12]
2. Each firm will start searching the information signals of firms close by and move on to search and evaluate signals of firms further away from itself until the marginal cost of searching the next furthest firm exceeds the constant marginal benefit. There will be a distance, d_{ij}^* such that $\forall j, d_{ij} \leq d_{ij}^* \Leftrightarrow j \in \Omega_t^i$.
3. The total profit from searches and the total number of searches conducted by a firm will be larger the more firms are searched and the closer these firms are to firm *i*, i.e. the larger $\left|\Omega_t^i\right|$ for any given d_{ij}^*, and the smaller d_{ij}^* for any given $\left|\Omega_t^i\right|$.

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[11] Assuming that the only way firm *j* can become an element of Ω_t^i is through the evaluation of *j*'s information signal by *i*.

[12] This pre-supposes that firms use up space and cannot locate in the same place so that only a limited number of firms *j* can locate at any distance d_{ij} from firm *i*.

Clustering therefore is a profit-maximising location choice for every cluster member. While the social optimum is achieved with the location of all firms in one cluster, the number and size of clusters that constitute Nash equilibria is dependent on the number of firms, $|A|$, and the distance for which a firm finds it optimal to evaluate other firms' information signals, d_{ij}^*. One can expect that one determinant of which points in space are likely to be centres of agglomeration for innovative activity will be the location of production (AUDRETSCH & FELDMAN, 1996).

5 Next Steps

5.1 Theoretical Extensions

For reasons of brevity and simplicity I make a number of assumptions which limit the scope of the analysis. It will be the objective of further work to explore various extensions of this simple set-up.

One interesting extension would be to endogenise the number of firms $|A|$, which are taken as exogenously given in this paper. This would allow to integrate the notion that the new knowledge vector of a firm has a revenue potential in the knowledge market. The expected value of this revenue is increasing in the number of firms that potentially have an interest in acquiring this knowledge. This acts to stimulate firms' R&D expenditure above the optimal level in the current version of the model.

A further extension is to consider a dynamic setting in order to analyse the evolution of the size, structure and composition of clusters. For this purpose it would be interesting to look at the development of $\vec{k}_t^j$ of the different firms: The wider the spectrum of directions of existing knowledge vectors, $\beta(\vec{k}_{t-1}^j), j \in A$, the higher the probability that the producing firm can realise a decent revenue from its new knowledge even in case of a realisation of its new knowledge vector, $\vec{n}_t^i$, of less than expected complementarity. If one allowed firms to choose $E_t\beta(\vec{n}_t^i)$, , i.e. the expected direction of the new knowledge output of their own R&D, as one of the characteristics of their knowledge production function f_t^i in each period t, this would allow to analyse the composition and evolution of activities that will result from profit-maximising behaviour within a cluster.

A further interesting extension would be to introduce firm heterogeneity. Consider the case where firms have differing probability distributions for $\beta(\vec{n}_t^i)$ for instance because groups of firms have different knowledge production functions, f_t^i. The consequence would be low expected values for the realisation of $\alpha(\vec{k}_{t-1}^i, \vec{n}_t^j,)$ for firms within the same group but large expected values for the realisations of $\alpha(\vec{k}_{t-1}^i, \vec{n}_t^j,)$ for firms in different groups. These groups can be interpreted as different industries. A firm might be able to distinguish which other firms are members of the same group by observing patterns in the realisations of other firms' new knowledge vectors in previous periods, assuming that the knowledge production technology does not change significantly over time.

To the extent that the existence of firms with different orientations helps to hedge the risk inherent in innovative activity, namely of inventing new knowledge which is unsuitable for own exploitation, the dynamics discussed above might be a driver for inter-industry clustering.

A final extension concerns the limits to the size of clusters. Simple simulation exercises (not included in the current version of the model) have shown that critical cluster size emerges as a function of search costs and benefits. Clusters below the critical size threshold become unsustainable and consequently every multi-cluster Nash equilibrium in the location game consists of clusters of a size above this threshold. Interestingly, critical cluster size is a direct function of costs of information transmission and the distance within which firms find it useful to evaluate information of other firms, so that potentially interesting policy implications might be derived from this approach. Furthermore, specific growth patterns for clusters are discernable from these simulations which also might be useful for policy makers, for instance: The preliminary simulation studies show that clusters expand in sub-clusters in certain directions, rather than in ring form, and have the potential to develop self-enforcing dynamics.

5.2 Empirical Evaluation

Possible markets in which knowledge trades are internalised are the M&A market, the labour market and the market for co-operations. With regard to the M&A market, clustering could be viewed to help alleviate what HAGEDOORN & DUYSTERS (2000) call the "inspection problem" with M&As. This argument is consistent with studies by GRANSTRAND *et al.* (1992), LINK (1988), and MACDONALD (1985) who suggest that M&A is an important element in the technology acquisition strategy of companies, particularly in R&D intensive industries.[13]

For an empirical evaluation of the view put forward in this paper, future research should turn to identifying and empirically evaluating the candidate markets in which firms trade new knowledge.

6 Conclusion

The theory presented in this paper helps explain the finding that economic activity clusters more strongly in industries where new knowledge is more important. (AUDRETSCH & FELDMAN, 1996; HILPERT, 1992). Contrary to AUDRETSCH & FELDMAN's (1996) interpretation, however, we show that this finding need not be explained by recourse to knowledge spillovers but might be a consequence of the specific characteristics of new knowledge in innovative production (SIEVERS, 2005). Viewed from this angle, the observed phenomenon is explained as the response of profit-maximising firms to informational imperfections when knowledge is perfectly excludable. As discussed above this is also in line with more recent micro-level empirical studies critical of "black box"-type knowledge spillover arguments (e.g., ZUCKER, DARBY, & ARMSTRONG, 1998).

The motive for clustering proposed in this paper has not been discussed in the literature before. If the costs of gathering and evaluating information are increasing with distance between sender and receiver, clustering follows as the profit-

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[13] While studies like DE JONG (1976) and CHAKRABARTI & BURTON (1983) suggest that technology is not or only moderately important as a motive for M&A activity.

maximizing choice of the rational firm. This provides a motive for clustering of innovative activity under the assumption that only information about the characteristics of the respective knowledge and not the knowledge itself is diffused within a cluster. A plausible rationale for such a view is that the further away the receiver is from the sender, the more effort is necessary on behalf of the receiver to interpret and evaluate the information signal of the sender. As a consequence, one can expect close to perfect information diffusion within a cluster but increasingly imperfect diffusion between firms which are further apart from each other. Furthermore, the motive for clustering in this model is independent of the potential role of forward and backward linkages or the presence of Marshallian intra- or Jacobian inter-industry externalities (JACOBS, 1969; MARSHALL, 1920). It is derived by taking the special characteristics of new knowledge in economic activity seriously, in particular the importance of complementarity and uncertainty in innovative production, and is therefore of particular relevance to economic activity where new knowledge is important.

The view of clustering in this paper is that it can affect individual firms by changing the information structure. In particular, clustering facilitates the evaluation of information about other firms' new knowledge, thus alleviating informational imperfections hindering the efficient allocation of resources.[14] Clustering facilitates the evaluation of information signals because it favours and develops exchanges between firms and employees on formal and informal levels, for instance through social networks, hiring and firing of employees or by facilitating cooperation through social trust. The diffusion of information is spatially limited due to search and friction costs, that increase with distance, and because the main channels for information flows are networks of local character.

Importantly, this type of information diffusion is not to be confused with knowledge spillovers. The latter phenomenon is a costless transfer of an asset, namely knowledge, and the source of market failure, typically leading to under-provision.

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[14] The notion that the presence in an agglomeration reduces the costs of information exchanges also appears for instance in APPOLD (1995).

In contrast, the diffusion of information about firms' research output within the cluster eliminates an informational source of market failure and opens the door for efficiency improvements. In this paper clustering helps to provide the basis for efficient market outcomes by mitigating a reason for market failure. Once the information about other firms' new knowledge vectors is revealed through the cluster, the market can efficiently re-allocate new knowledge.

Appendix

Tab. 1 Empirical Observation with Regard to Innovative Activity Contingent on the Assumptions with Regard to Knowledge and Information Diffusion

		knowledge	
		locally non-exclusive	**fully exclusive & appropriable**
cost of transmitting information about new knowledge	**invariant to distance**	*Clustering (AUDRETSCH & FELDMAN, 1996)*	*No clustering*
	increasing in distance	*Clustering*	*Clustering*

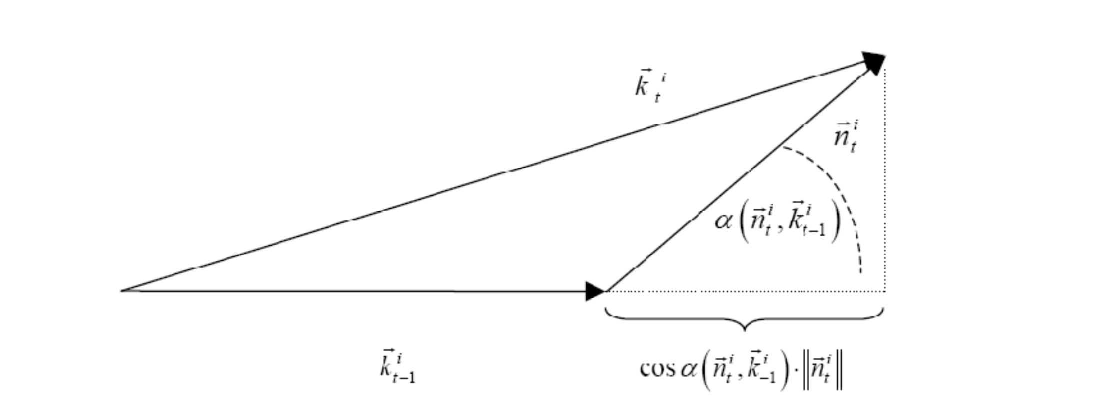
Notes: "Clustering" here denotes the observation of a concentration of innovative activity in excess of the geographic concentration of production in the respective industry.

Tab. 2 Characterisation of the Innovative Firm

Frim *i* at time *t*	Length of the new knowledge vector of *i*, $\|\vec{n}_t^i\|$
	Direction of the new knowledge vector of firm *i* relative to the existing knowledge vector of firm *j*, $\alpha\left(\vec{k}_{t-1}^j, \vec{n}_t^i\right)$
	Information signal about $\vec{n}_t^i$ available to firm *j*, $s_t^j\left(\|\vec{n}_t^i\|, \alpha\left(\vec{k}_{t-1}^j, \vec{n}_t^i\right)\right)$

Source: Own illustration.

Fig. 1 Cumulativeness and Complementarity with Vector Representation

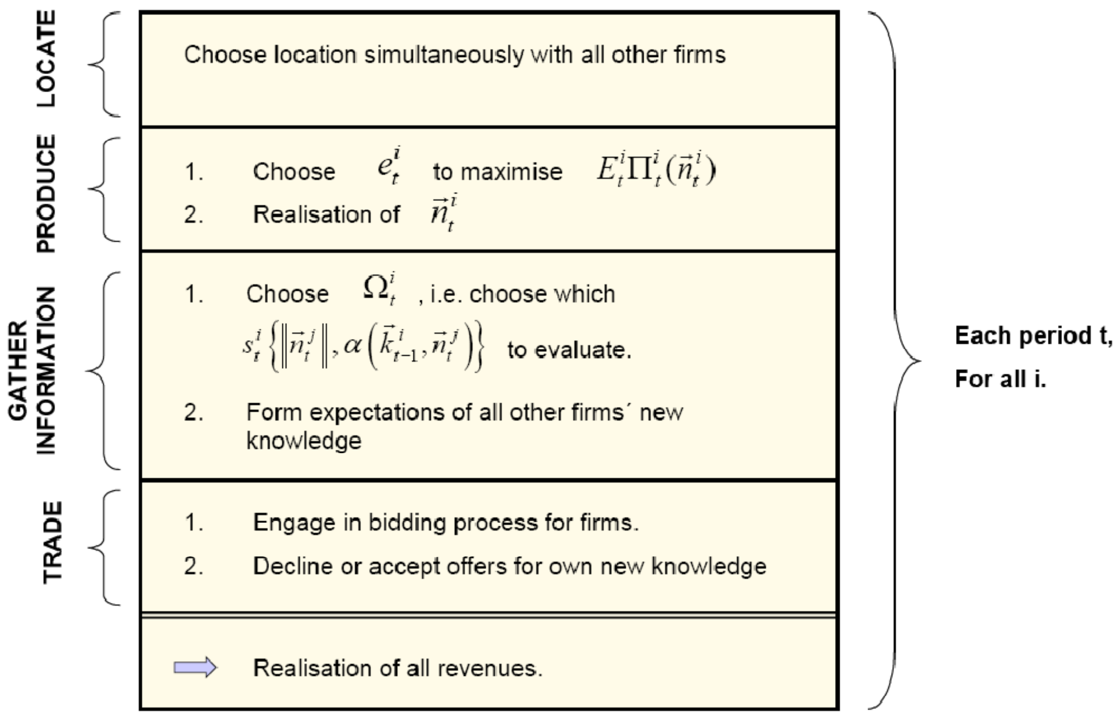


$\vec{k}_t^{\,i} = \vec{k}_{t-1}^{\,i} + \vec{n}_t^{\,i}$, and

$$\left\|\vec{k}_t^{\,i}\right\| = \sqrt{\left\|\vec{k}_{t-1}^{\,i}\right\|^2 + 2\cdot\left\|\vec{k}_{t-1}^{\,i}\right\|\cdot\left\|\vec{n}_t^{\,i}\right\|\cdot\cos\alpha(\vec{n}_t^{\,i}, \vec{k}_{t-1}^{\,i}) + \left\|\vec{n}_t^{\,i}\right\|^2} \leq \left|\vec{k}_{t-1}^{\,i}\right| + \left\|\vec{n}_t^{\,i}\right\|.$$

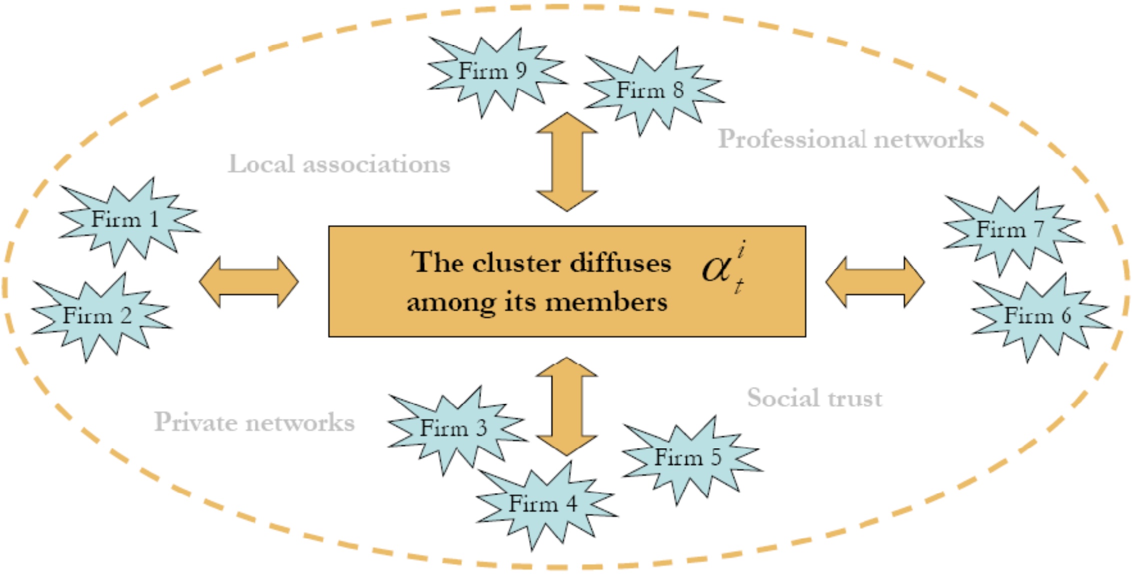
Source: Own illustration.

Fig. 2 The Order of Play



Source: Own illustration

Fig. 3 Clustering Alleviates Informational Imperfection



Source: Own illustration.

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