JENA ECONOMIC RESEARCH PAPERS

2008 – 070

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www.jenecon.de

ISSN 1864-7057

The JENA ECONOMIC RESEARCH PAPERS is a joint publication of the Friedrich Schiller University and the Max Planck Institute of Economics, Jena, Germany. For editorial correspondence please contact markus.pasche@uni-jena.de.

Impressum:

Friedrich Schiller University Jena
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D-07743 Jena
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September 2008

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Abstract

Industrial clusters develop regionally along the industry's lifecycle and typically exist over many product generations. In order to maintain their innovativeness, they have to develop and adjust along the industry lifecycle. We conduct 142 depth face-to-face interviews in clusters across two continents to examine the drivers of a cluster's innovativeness along the industry lifecycle. The results from our interviews suggest that the impact of key drivers of cluster innovativeness change depending on the stage of a cluster's underlying industry lifecycle. Classifying clusters as either being adolescent (information technology, biotechnology) or mature (automotive, chemicals), our regression analyses show a changing influence of cluster patterns along the industry lifecycle on a firm's innovativeness. Specifically, we analyze the impact of interorganizational network strength, openness, university collaboration, and intrapreneurship on radical innovation across adolescent and mature clusters. Implications for research and policy makers are discussed.

JEL-classification: O18, R12, L6

Keywords: Cluster, Industry Lifecycle, Innovation

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1. Introduction

Clusters in the sense of regional concentrations of firms of the same or related industries along with supporting institutions are often seen as the birthplace of important innovations that, eventually, drive economic development (Bell, 2005; Lawson and Lorenz, 1999; Porter, 1998; Tallman and Phene, 2007; Tallman et al., 2004). Not surprisingly, cluster policies have become a prominent means of fostering innovation leading to a strong interest in the impact of cluster patterns on innovation (Porter, 2003). On top of traditional Marshallian pecuniary advantages of operating in agglomerations (cf. Marshall 1890), local knowledge spillovers are regarded as one of the key drivers of a cluster's innovativeness (cf. Audretsch and Feldmann 1996, and Jaffe et al. 1993). Given that industrial clusters develop regionally along the industry lifecycle and typically exist over many product generations, cluster innovativeness will be affected differently by various drivers depending on the stage of the cluster's maturity. However, the extent to which the effects of different drivers of cluster innovativeness change with cluster maturity has not yet been examined empirically. In this article, we combine a discovery-oriented approach based on 142 depth interviews with a paper-based survey to provide an answer to the question whether and to what extent the impact of different drivers of cluster innovativeness changes with cluster maturity

The attractiveness of clusters has brought at least two different disciplines to the scene; geographers and economists. While the combination of economic action within geographic regions certainly promises gains from interdisciplinary cooperation, intellectual exchange between the two disciplines has, until recently, been rather scarce and was coined by an atmosphere of skepticism, reservations, or simply ignorance (Duranton and Storper 2006). In the field of agglomeration economies and hence clusters, Rigby and Essletzbichler (2006) relate geographers' underlying concerns to the stable and frictionless equilibrium setup of economic models that might ignore interesting aspects of geographical variation and dynamics. At this point, geographers overlap with economists studying dynamic processes in the field of industry evolution (e.g. Nelson and Winter 1982), in particular the lifecycle approach to describe an industry's evolution as introduced by Gort and Klepper (1982) and further formalized by Klepper (1996). Based on detailed analyses for entire industries, Klepper finds similar characteristics of industrial evolution over and over again: (1) incumbent firms usually give involuntarily birth to new firms, so-called spin-offs. This occurs when incumbents' employees are for some reason dissatisfied and decide to start their own business; (2) in this process, successful incumbents are more fertile and their offspring is also likely to be successful, leading to an inheritance of traits; (3) spin-offs are likely to locate in close proximity to their parents, which explains the evolution of industry clusters and their dynamics in certain regions (cf. Klepper and Sleeper 2005; Klepper and Thompson 2006).

This evolutionary interpretation of processes within clusters suggests changing patterns along the industry lifecycle (cf. Audretsch and Feldman 1996). Industrial clusters usually exist over many product generations and therefore have to identify new ways of reinventing and maintaining their innovativeness while coping with a changing environment at the same time. To learn about the structure of industrial clusters, we develop a framework based on Klepper's (1996) idea of the industry lifecycle and argue that clusters at an early stage of the industry lifecycle still change rapidly and are thus in an adolescent stage. In this early phase, products and processes are not yet standardized so that cluster openness to new members and actors outside a specific cluster as well as heterogeneity within a cluster provide access to a broad range of ideas for innovations and improvements. Industry-university relationships are also likely to play an important role in driving a cluster's innovativeness in adolescent clusters. However, with increasing maturity, industry clusters become more streamlined as exchange relationships, products and procedures are increasingly standardized. In the mature phase, the strength of a cluster's network ties becomes increasingly important in the focused innovation process as they allow for close cooperation and informal knowledge flows based on trust (cf. Dei Ottati 1994; Williamson 1999; Lublinski 2003). This leads us to the hypothesis of a changing impact of cluster patterns, such as interorganizational relationship strength and openness, industry-university collaboration, and intrapreneurship (intraorganizational orientation toward entrepreneurial activities) on a firm's innovativeness across adolescent and mature stages of a cluster.

To test this, we conducted 142 depth face-to-face interviews in ten industrial clusters across two continents. More specifically, over a period of eighteen months, we conducted depth interviews with managers of firms across four different industry contexts, namely: (1) automotive, (2) chemicals, (3) information technology, and (4) biotechnology. Based on our initial findings from the interviews, we then use a survey to analyze the changing pattern of clusters along the industry lifecycle. Grouping clusters along the industry lifecycle and using a cluster fixed effects regressions framework, we find evidence for a changing impact of interorganizational relationship strength, openness, university-industry collaboration, and intrapreneurship on a firm's innovativeness across adolescent and mature clusters. Specifically, in adolescent clusters, the collaboration between universities and industry positively affects the innovativeness of cluster members, whereas interorganizational strength and intrapreneurship have a negative impact. Conversely, in mature clusters university-industry collaboration has a negative effect on the innovativeness of cluster members, whereas interorganizational relationship openness has a positive impact.

The paper is organized as follows. In Section 2, we link the industry lifecycle approach to the evolution of industry clusters to examine how the patterns in these clusters change over the lifecycle and look at the changing impact of cluster patterns (i.e., interorganizational relationship strength/openness, university-industry collaboration, and intrapreneurship) on firm innovativeness across adolescent and mature clusters. In Section 3, we discuss our method and data to test our proposed model. Before turning to the quantitative results from our regression analyses (4.2), we first present qualitative information from the interviews on the effects of cluster patterns on the innovativeness of cluster members along the stages of cluster maturity (4.1). To conclude, we discuss implications for research and policy makers.

2. The Industry Lifecycle and the Evolution of Clusters

Industry Lifecycles

Klepper (1996) describes how the sources of knowledge and innovation change over the lifecycle. He argues that during the early and adolescent phases of an industry lifecycle, most product innovations originate outside the current set of producers (e.g., from firms in technologically related markets, by way of independent inventors, etc.). In this period, innovative entrants play a crucial role. In later and more mature phases of the lifecycle, however, innovations are more likely to originate from a process of learning by doing, resulting in ongoing incremental innovations (Harhoff 2008). Incumbents not capable of repeated innovations will exit the market, leading to increased concentration. Hence, entry at this stage is most likely to originate from spinoffs concentrating on niche markets too small or unprofitable for their parent firms (Klepper and Sleeper 2005) or from spinoffs by former employees starting their own business (Klepper and Thompson 2006). These spinoffs are likely to locate in close proximity to their parent thereby increasing competition and industrial concentration.

Assessing this theory of the product lifecycle and its applicability to the industry level, we believe that in early stages of the lifecycle the number of products and the number of competitors in the industry initially increases with ongoing experimentation. Each product can gain sufficiently high market shares to cover its fixed costs. In these adolescent stages of the industry lifecycle, every new product extends the existing product range and does not necessarily replace or cannibalize existing products. Accordingly, product variety is likely to increase. However, with ongoing standardization of the production process over time, products become increasingly homogenous. New products then replace, rather than add to, the existing product range, and the number of products stabilizes in later lifecycle stages. New products embody best-practice technologies advancing at a certain rate and each new product embodies new capabilities at a lower price (Greenstein and Wade 1998). Accordingly, the identity of the industry leaders remains largely unchanged, while there are frequent new product introductions.

Turning to the firm level, cannibalization is only advantageous if expected profits from the new product overcompensate the losses from replacing the existing product (cf. Cohen and Klepper 1996a, 1996b). By contrast, profits from existing products remain unchanged when a new product complements the existing product range. This holds as long as the volume of sales of the new product is not related to the volume of sales of existing products which is plausible in the early stages of a lifecycle. With products becoming more homogeneous along the industries lifecycle, new products will always (at least partially) cannibalize profit of existing products as competition also becomes fiercer. In such a situation firms are willing to cannibalize an own existing product by innovation in order to stay competitive – a strategy that Aghion et al. (2004) call an escape competition strategy and that will serve us as a cross-check for an interview-based categorization of the industries as either being in an adolescent stage or in a mature stage of the lifecycle.

<u>The Evolution of Clusters and the Governance of Innovation</u>

According to the control rights perspective, openness helps to move ideas from one stage to the next as it reduces search costs by next stage researchers (Aghion et al., 2005). To the extent that basic research tends to be less focused and more diverse, openness is likely to be more valuable in basic than in applied research. We posit that the two stages of research—basic vs. applied—can also be interpreted in terms of the industry lifecycle. In the early stage of the lifecycle, research is more diverse. Taking the control rights perspective, openness should be more conducive to research in this stage. As the head of research & development of an information and technology (IT) company put it:

> *In the early stages of a project, we need to be very open. Often we do not know where to start. Covering a lot of grounds and keeping our minds open to different alternatives just makes sense.*

Managerial decision makers can gain a deep understanding of fundamental principles underlying current technologies and are thus in a better position to estimate future areas of growth. In interviews, business leaders across industries admitted that they often were forced to make “quick and dirty” decisions based on insufficient data and information. Fundamental understanding of phenomena can help managers avoid speculative solutions and take better decisions overall. Especially small and medium-sized enterprises lacking sufficient funds to invest in own research and development projects will benefit from collaborations with research organizations. In later stages of the industry lifecycle, however, research tends to become more focused, routinized, and commercially-minded. This has implications for the structure of industrial clusters along the lifecycle. Adolescent clusters are characterized by openness and various weak ties linking the diverse actors, and knowledge spills over across firms. Moreover, universities along with private and public research institutes are important and guarantee the inflow of latest knowledge to the cluster firms’ knowledge stock.. Conversely, in more mature stages of the industry lifecycle the cluster’s pattern increasingly converges into a hierarchical hub-and-spoke structure (Markusen 1996), where one or a number of key firms act as the hub while smaller firms along the supply chain assemble around them. This structure is characterized by strong ties between the hub firm and its spokes. These clusters are less open and the innovation process increasingly becomes a routine (Nelson and Winter 1982) of large firms with routinized research laboratories.

In mature clusters, research tends to be more target-oriented and cooperation with universities and scientific research institutes may become less desirable as protecting the own knowledge stock gains importance. In stages of adolescence, industry-academic research collaborations can create synergies that facilitate access, and thus enhance opportunity scanning, foster outreach, and agility to innovate. For example, the CEO of a large IT company said:

> *Collaboration with university labs is very practical. And it is good business practice. But once we have a good idea about what we are after, we are often faster when going it alone. The protection of intellectual property is always an issue but more so in later stages when we know what we want to protect.*

Geographic clusters of economic activity may develop tendencies towards homogeneity, group-think and, consequently, suffer from lock-in effects and ossification (McFadyen and Cennalla, 2004). Potential lock-in effects are likely to harm the competitiveness and performance of actors within a cluster for a number of reasons. First, they may reduce actors' overall alertness to environmental change. Because actors may not be aware of changing economic circumstances, they are less likely to innovate and, consequently, overall innovativeness within a cluster decreases. Second, homogeneous groups of companies require a less diverse set of suppliers, services and exchange partners. As most businesses tend to make use of similar exchange partners, concentrated levels of exchange with few partners may inhibit knowledge creation as well as access to new opportunities. As a result of this, there may be less incentives and hence potential for change and innovation of incumbent firms (intrapreneurship) within a cluster. Eventually, this situation induces the spinoff process described by Klepper and Thompson (2006) where employees working for incumbents choose to start their own venture, a spinoff, when they disagree with management decisions on which projects should be pursued. However, the existence of large firms' venture capital branches indicates at the same time that incumbents are interest in staying connected to their spinoffs which are often located in proximity to their parent firms.

In summary, we argue that the collaboration between university and industry will be of particular importance to firms' innovativeness in adolescent clusters. Further, interorganizational relationship strength and intrapreneurship will have varying effects on firm innovativeness depending on cluster maturity. While openness is regarded to be of special importance in early stages of the lifecycle where it guarantees the inflow of new knowledge, the interest of firms to stay connected to their spinoffs indicates that openness still plays a role in mature stages of the lifecycle.

3. Data and Method

To examine the changing impact of cluster patterns along the industry lifecycle on a firm's innovativeness, we employ a combination of a discovery-oriented approach and survey method. More specifically, we conducted 142 face-to-face depth interviews in ten industrial clusters across two continents to ask open-ended questions and learn about firms' interactions within a cluster. Over a period of eighteen months, we conducted depth interviews with managers of firms across different industry contexts: (1) automotive, (2) chemicals, (3) information technology (IT), and (4) biotechnology. Based on our initial findings from the interviews, we generated items for our scales and developed a survey to test firms' willingness to cannibalize, focus on radical innovation, extent of collaboration with universities, the strength and openness of their interorganizational relationships as well as intrapreneurship, i.e. their intraorganizational orientation toward innovation (*intra*). We pretested our questionnaire in two clusters and revised a number of scale items based on discussions with 12 managers. We therefore did not include the results from our 2 pretest clusters in the regression analysis. Our final sample then consists of 194 observations from 8 clusters.

Each of the themes mentioned above is covered by a set of questions in the survey (see Appendix A). Each of the questions is answered on a scale ranging from 1 to 7. To avoid problems of mulitcollinearity in the econometric analysis, each of the themes is condensed to a single indicator by a principal component analysis resulting in six indicators reflecting the firms' radical innovativeness (*inno*), willingness to cannibalize (*can*), collaboration with universities (*uni*), the strength (*strength*) and the openness (*open*) of the firms' interorganizational relationships, and the firms' focus on intrapreneurship, i.e. a tolerance to intraorganizational initiatives (*intra*). Table 1 shows some descriptive statistics of the six indicators. The scale from 1 to 7 meets the needs of a principal component analysis (cf. Martin et al. 1974).

Table 1: Means by clusters

Cluster	*inno*	*can*	*uni*	*strength*	*open*	*intra*
Canada						
Biotechnology (N=21)	-0.75	-2.54	-3.22	-2.92	0.57	-0.42
IT (N=27)	0.65	-0.42	-0.47	-0.26	0.47	0.34
Automotive (N=23)	-0.15	0.60*	0.84	0.62	-0.22	0.52
Chemicals (N=24)	0.16	1.95*	2.45	2.20	-0.34	-0.21
Austria						
Biotechnology (N=24)	-0.45	-1.93	-2.47	-2.12	1.14	-0.36
IT (N=31)	0.43	-0.17	-0.24	-0.09	-0.92	0.09
Automotive (N=22)	-1.31	0.79*	1.05	0.80	-1.04	-0.07
Chemicals (N=22)	1.09	1.73*	2.07	1.70	0.55	0.01
Overall (N=194)	0.00	0.00	0.00	0.00	0.00	0.00
Eigenvalue	3.12	2.42	3.73	2.98	2.93	2.86
Difference	2.67	2.09	3.20	2.52	2.43	2.24

* above median

The eigenvalues of each principal component and the difference to the respective second principal component show that for each of the six indicators the first component already sweeps up the largest variation in each complex of questions.

As confirmed by interviewees, biotechnology and information technology are considered as being in an adolescent stage of the industry lifecycle, while automotive and chemicals are in a more mature stage (see also Svensson, Henning et al. 2008). As the CEO of a chemical company put it:

> *I operate in a highly mature market. All the great players have a rich history and we do not see a lot of newcomers.*

In contrast, the CEO of a biotechnology company mentioned:

> *We see a lot of change happening in our industry. New companies are being set up and others are being bought by competitors. Maybe things will be different when our industry reaches maturity, but we are not there yet. Core technologies tend to change fast.*

Looking at our cannibalization indicator (*can*), we find that it takes on average a value below median in biotechnology and information technology clusters while it takes on average a value above median in automotive and chemicals clusters. This explorative assessment supports our findings from the interviews that automotive and chemicals are thought to be in a mature stage, whereas biotechnology and IT are considered to operate in an adolescent stage. This leaves us with two clusters – biotechnology and information technology – in the adolescent stage of the industry lifecycle and two clusters - automotive and chemicals – in the mature stage of the industry lifecycle across Austria and Canada.

We now examine the changing impact of cluster patterns on a firm’s innovativeness across adolescent and mature stages of the industry lifecycle. The focus on a firm’s innovativeness is due to at least two facts: From a policy perspective, cluster policies are often targeted towards shaping cluster characteristics to enable firms to innovative persistently within the cluster.

From a theoretic perspective, Section 2 underpins that cluster characteristics are directly linked to innovation.

Cluster patterns are measured by four indicators: *uni* captures the firms' collaboration with universities, *strength* captures the strength of ties between actors, i.e. whether weak or strong ties are dominant in the cluster, and *open* combines survey questions on collaboration with different types of firms (age, size, industry, geography, etc.). At first glance, it is not obvious whether this indicator should be especially pronounced in adolescent or mature industrial clusters. Indeed, in an adolescent stage collaboration with firms from different industries may be of special importance; however in more mature stages collaboration with firms along the supply chain or with own spinoffs may gain importance. Finally, *intra* captures intrapreneurship, i.e. firms' intraorganizational orientation toward innovation. All indicators are measured on the firm level to account for within-cluster differences in the perception of cluster openness. As discussed above, we assume that the impact of the cluster openness on a firm's innovativeness changes along the lifecycle. All this results in the following estimation equation:

$$\begin{aligned} inno_{ic} &= \alpha_c + \beta_1 d_{ado} uni_{ic} + \beta_2 d_{ado} strength_{ic} + \beta_3 d_{ado} open_{ic} + \beta_4 d_{ado} \operatorname{int} ra_{ic} + \\ &+ \beta_5 d_{mature} uni_{ic} + \beta_6 d_{mature} strength_{ic} + \beta_7 d_{mature} open_{ic} + \beta_8 d_{mature} \operatorname{int} ra_{ic} + \varepsilon_{ic} , \end{aligned} \tag{1}$$

where the subscript *i* indicates the respective firm and *c* indicates a cluster within a country. Consequently, α_c are cluster fixed effects to capture firm-invariant unobserved heterogeneity between clusters — including unobserved cluster- and country-specific institutions (cf. Porter 1998) — that could bias the results. Finally, d_{ado} and d_{mature} are dummy variables that take value one if the respective cluster is categorized as being in an adolescent and mature lifecycle stage respectively. Equation (1) can be estimated by standard least square methods. To account for the anticipated serial correlation between firms within a cluster, cluster-robust standard errors are calculated (Huber 1980 and White 1967). Before turning to quantitative results from our regression analyses in section 4.2, we present qualitative information from the interviews to document changing cluster patterns along the industry lifecycle.

4. Results

4.1 Qualitative findings

By providing openness needed to develop new knowledge and innovation, academic research institutions, such as universities and teaching hospitals among others, can contribute substantially to the agility of, and innovation in, geographic clusters. In our study, we observed that academic research institutions can act as catalysts of innovation and consequently business activity within geographic clusters. At that, we identified firms in adolescent clusters as more open to collaborations with universities.

Researchers at university or other academic institutions are frequently embedded in global innovation networks, forming highly focused groups of shared interests. In addition to their international linkages across the globe, these research groups are continuously able to attract the most promising talents in the field. By offering access to a global network of expertise, academic research institutions can help members of adolescent clusters obtain greater exposure to wider knowledge at less cost. Specifically, with rising research and development costs, in adolescent clusters actors' ability to trade upon an international network of brain power will take on added significance. As the director of a biotech start-up hospital put it:

> *Duplications of research efforts are a tremendous waste of resources. We do not necessarily need ten teams working on exactly the same problems. By connecting and combining the human brain power and economic resources at different centers around the world, we are able to develop results that would not be able otherwise. The synergies gained from collaboration must not be underestimated. They are huge.*

In addition to this, the manager at a large IT company underscored the importance of international collaboration amongst researchers in the face of global research activities, resulting in shorter invention and development cycles:

> *The principle behind a cluster is that it serves as a lightning rod, pulling in actors and activities. In addition to the strength of links among actors within the cluster, we need a bridge to people and all the activities going on outside the cluster – especially at an early stage. The expertise and talents of others may not necessarily reduce my market value. On the contrary, I can benefit as long as I am willing to make use of it. For example, a business may be interested in my technology. Now, I can draw on my own research but I can also draw on the expertise of all my colleagues who may have something bundle-able. In the end, it allows me to offer a more valuable and stronger package.*

During the interviews with managers of private companies, directors of academic research institutions, and incubators in various industry clusters, we observed that managers of private firms are particularly interested in commercializing intellectual property developed through industry-university collaborations in the early stages of an industry. By taking advantage of linkages between research teams in industry and academia, both sides can benefit from important synergies. However, private firms engage in such collaboration more openly in adolescent clusters. More specifically, because of pressures to deliver, private organizations often have less time to devote resources to basic or fundamental research in adolescent clusters. By collaborating with universities, teaching hospitals and other academic research centres, companies may gain access to the latest advances in their particular field of interest at lower cost. First, researchers at universities frequently co-operate with other partners in global research and innovation networks and are thus aware of the latest progress made in their field. Access to these webs of fundamental research can be a crucial source of competitive advantage for firms, as interview participants suggested that loci of R&D as well as competition in today's research environment were not individual people or individual teams but research networks composed of people working in different institutions around the globe.

The ability to spot market opportunities and leverage collective resources and synergies may be especially critical in adolescent clusters where firms have yet to build strong relationships with exchange partners. Lacking strong ties, firms are more open to a diverse set of exchange partners. As mentioned before, companies often do not have enough time to devote sufficient resources to fundamental research that may lead to the development of radical innovations in the future. Fundamental research, in contrast, is the raison d'être for most scientists at universities, hospitals and other academic research centers. By combining fundamental academic research with time-based competition in companies, the agility of actors within clusters may be greatly enhanced. As the CEO of a globally operating IT company put it:

> *Survival is not about lucky shots but mainly about pipelines of innovation that enable businesses to upgrade products and service offerings on a continuous basis. Academics are capable of doing cool stuff. I am thinking of opportunities, you know, of win-win situations, as opposed to zero-sum games, and of expanding the market as a whole. In the end I always prefer to share a great, rich cake with someone else than having a tiny, dry cake for myself.*

Although complementarity of strategic resources creates the potential of rents, these may only be unlocked if exchange partners possess sufficient co-ordination and problem-solving skills. In our interviews, we observed that actors in mature clusters tend to talk about strong ties with exchange partners more frequently than interviewees in adolescent clusters. More specifically, interviewees in mature clusters frequently highlighted the benefits of strong ties because of improved compatibility in decision processes, information, and control systems. It was argued that repeated interaction helped firms reduce costs time-to-market. Moreover, interviewees in mature clusters underscored the role of trust and willingness to coordinate production and development processes. For instance, the executive of a chemicals company said:

> *It is extremely helpful that we know our exchange partners. I feel perfectly comfortable outsourcing as much as we can. The only thing we can afford at the moment is focus.*

Networks characterized by weak links may be sufficient for the transfer of information that is easily codified. However, multilateral ties among members and processes for transferring know-how are important where the meaning of information is uncertain and ambiguous. In mature clusters, actors appear to trade upon strong interorganizational relationships that create trust and thus help to overcome uncertainty in production processes. Moreover, strong ties between organizations provide channels through which actors learn about others' competencies and reliability. To the extent that actors had more time to interact in mature clusters and processes become standardized, members of a mature cluster engage in strong relationships more often. Interviewees also emphasized strong relationships to foster reciprocal learning by increasing the willingness and ability of firms to engage in a mutual exchange of know-how. As the executive of a global firm operating in the automotive industry noted:

> *Most communication is non-verbal. In this place, people share a common sense of collegiality. What it really comes down to is building a relationship between people. It makes it an easier dialogue.*

And the General Manager of a chemical company shared the following:

> *If you can talk to people directly, the problem will be dissolved immediately. And because I have an idea of what others are doing, it is far more straightforward and less complicated to find, and talk to the right person. With chronic connectivity, business can be made to work.*

In summary, qualitative findings from our interviews suggest that cooperation with universities is especially supportive to innovation in clusters in adolescent stages of the industry lifecycle. In mature stages of the lifecycle, cluster members especially highlighted the importance of strong ties with exchange partners that improved compatibility in decision processes and eventually the innovation process.

4.2. Quantitative findings

Table 2 reports the results of the least square estimation with cluster robust standard errors. Cluster fixed effects are not reported in the table and are available from the authors on request. The dependent variable is firm innovativeness (*inno*). The last column tests for the equality of the coefficients of the respective variables in the adolescent stage of the industry lifecycle and the mature stage of the lifecycle respectively. This indicates that all coefficients in the adolescent stage differ significantly from those in the mature stage.

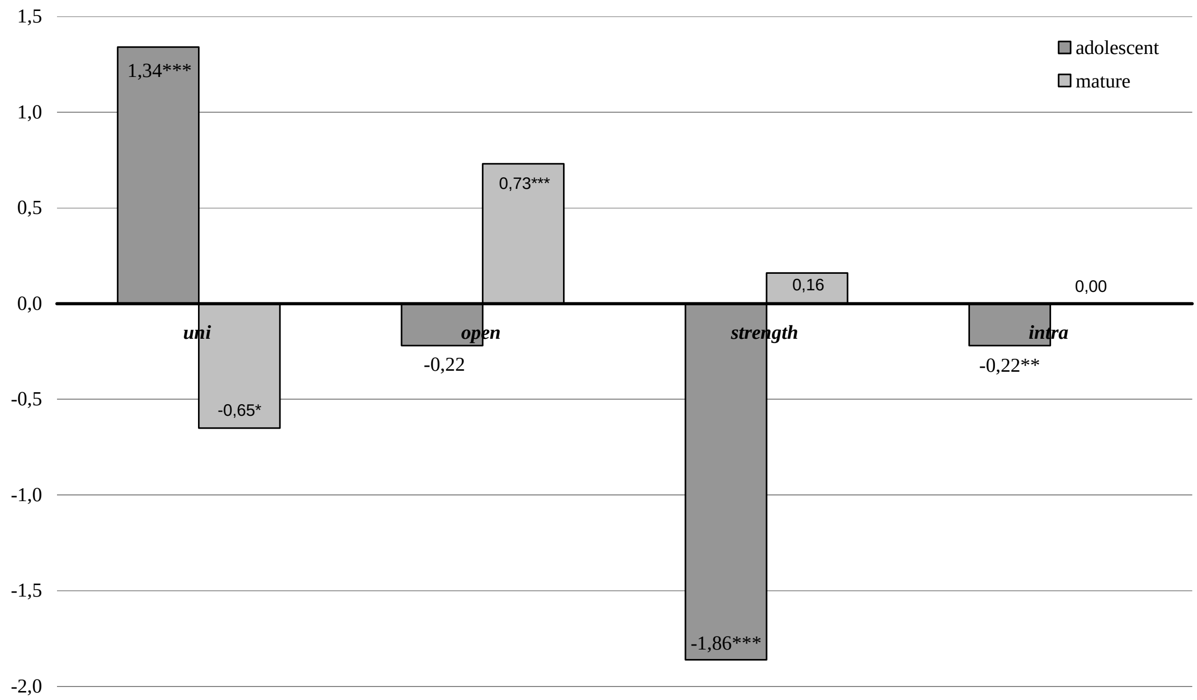
Table 2: Results

Variable	Coefficient	Robust Standard Error	Test of Equality of Coefficients
uni (adolescent)	1.34***	0.38	18.95***
uni (mature)	-0.65*	0.29	
open (adolescent)	-0.22	0.12	49.98***
open (mature)	0.73***	0.06	
strength (adolescent)	-1.86***	0.34	22.83***
strength (mature)	0.16	0.25	
intra (adolescent)	-0.22**	0.09	4.57*
intra (mature)	0.00	0.05	
R^2	0.47		

Dependent variable: *inno*; cluster fixed effects not reported
*** statistically significant at the 1% level
** statistically significant at the 5% level
* statistically significant at the 10% level

Collaboration with universities (*uni*) has a significantly positive impact on a firm's innovativeness in the early stage of the industry lifecycle while it is significantly negative in the mature stage of the lifecycle. The latter finding is interesting, given the supposed positive effects of university-industry collaboration suggested by many cluster incubators. Our counterintuitive finding has important implications for policy makers. Specifically, subsidies or government policies intended to facilitate university-industry collaborations may have an adverse effect in mature clusters. Network strength (*strength*) is significantly negative in adolescent clusters while it is insignificant in mature ones. Both results are in line with the argumentation that the early phases of the lifecycle are characterized by experimentation and import of leading-edge knowledge from other actors, e.g. universities, as the own knowledge stock is still small. This effect disappears once the cluster matures. By contrast, openness (*open*) is only significantly positive in the mature stage of the lifecycle. This may be because firms in a mature industry are well connected with firms of different age, size, industry, or geography as a result of ongoing outsourcing due cost-saving pressures to stay competitive. Moreover, the danger of lock-in effects may be particularly strong in mature stages. Openness can counteract the lock-in effects of interorganizational relationship strength and, thus, drive the innovativeness of firms in mature clusters. Moreover, the willingness of parent firms to stay in close contact with their spinoffs may drive these results. Surprisingly, the coefficient on intrapreneurship (*intra*) is significantly larger in the mature stage than in the adolescent stage of the lifecycle. This may be due to the fact that entrepreneurial activities of employees are generally encouraged but not all ideas are commercialized in house, thereby inviting spinoffs (cf. Klepper and Thompson 2006).

Figure 1: Regression Coefficients for adolescent and mature clusters



5. Conclusions

An evolutionary interpretation for the emergence of regional clusters suggests changing patterns along the industry lifecycle. In adolescent stages, products and processes are not yet standardized and thus, openness and heterogeneity provide access to a broad range of ideas for innovations and improvements. With increasing maturity, industry clusters become more streamlined as cooperation partners have been found and products and procedures became settled. In this phase, the strength of a cluster's network ties gain in increasingly importance as they allow for close cooperation and informal knowledge flows based on trust.

Against this background, the paper's goal was to analyze the changing impact of cluster patterns on firm innovativeness across adolescent and mature stages of the industry lifecycle. To do so, we employ a combination of a discovery-oriented approach to detect clusters and collect information about the cluster firms and a survey method to analyze this qualitative information. Over a period of eighteen months, we conducted 142 face-to-face depth interviews in ten industrial clusters with firm managers across different industry contexts: (1) automotive, (2) chemicals, (3) information technology, and (4) biotechnology. All the clusters we examined shared a number of key characteristics in terms of age, skilled labor force, and proximity to key global markets. Based on our initial findings from the interviews, we ran a survey to analyze the changing patterns of clusters along the industry lifecycle. Grouping clusters by their stage of maturity and using a cluster fixed effects regressions framework, we find evidence for the changing impact of cluster patterns on a firm’s innovativeness. The key differences between adolescent and mature clusters are their respective network strength, openness, collaboration with universities, and the focus on intrapreneurship.

Our findings establish a base for further research and help refine cluster policies aiming to promote the emergence and survival of clusters. Specifically, our findings suggest that members of adolescent clusters have much to gain from open relationships, while this seems much less relevant in mature clusters. Accordingly, managers and academic researchers ought to be encouraged to identify and exploit processes to share, combine and create new knowledge and know-how.

There is a risk that in the pursuit of maximizing short-run results, the significant value that can be derived from industry-academic research collaboration is shelved and consequently lost. Thus, what we argue for is not industry-academic research collaboration for its own sake, but collaborative efforts among partners in industry and academia combined with a willingness to innovate. In addition to this, the current findings suggest a negative impact of university-industry collaboration in mature stages of clusters. Accordingly, we believe that policy makers need to critically evaluate the benefits of encouraging this form of collaboration through subsidies, research grants or other means when clusters have reached maturity. The findings can also help cluster incubators facilitate the exploitation of open relationships in adolescent clusters and the strengthening of relationships among members as clusters mature.

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Appendix A: Survey Description

Network Strength

1. This organization has long-lasting relationships with actors in this cluster.
2. We frequently meet with our exchange partners in this cluster to share resources and new ideas.
3. The contact with our exchange partners in this cluster is not very strong. *(reverse coded)*
4. The exchange relationships with our partners in this cluster are characterized by a high level of agreement and trust.

Network Openness

1. We are connected to a range of firms, differing in size, age, capabilities, and industry.
2. This organization readily accepts new members to its network of exchange partners in the cluster.
3. We are well-connected with actors outside this cluster.
4. Linkages with actors in this cluster are very difficult to reconfigure. (*reverse coded)*

Willingness to Cannibalize

1. We tend to oppose new technologies that cause our products/services to become obsolete (reverse coded).
2. We are willing to sacrifice sales of existing products/services in order to improve sales of our new product/service.
3. We do not pursue a new technology that causes existing investments to lose value (reverse coded).

Radical Innovation

1. We rarely introduce products/services that are radically different from existing products/services (reverse coded).
2. We lack behind in introducing radical product/service innovations (reverse coded).
3. The introduction of radically new products/services is of strategic importance to us.
4. We have managerial systems in place that encourage and reward the introduction of radical products/services.

University-Industry Collaboration

1. We encourage and reward the collaboration with universities and research institutes.
2. We actively seek to collaborate with universities and research institutes during new product/service developments.
3. We rarely collaborate with universities and research institutes during new product/service development stages (reverse coded).
4. We often initiate the collaboration with universities and research institutes.
5. We are not interested in collaborating with universities and research institutes (reverse coded).

Intrapreneurship (Intraorganizational Orientation Toward Innovation)

1. We celebrate a culture of entrepreneurship in our business.
2. In this company, we pride ourselves to be highly entrepreneurial.
3. We do not actively encourage and reward entrepreneurship among our employees (reverse coded).
4. We actively encourage and reward entrepreneurial efforts by our employees.