WHEN CRITICAL MASS CAN BECOME A MESS: A CONTINGENCY MODEL OF REGIONAL INNOVATION DYNAMICS

Daniel Örtqvist & Håkan Ylinenpää*
CiiR/Entrepreneurship & Innovation
Luleå University of Technology
SE 971 87 LULEÅ, Sweden

** Corresponding author*

A common argument for why some regions perform relatively worse in developing innovations is that they lack sufficient critical mass to compete relative other regions in the development of knowledge-economy innovations and business models. In this study we examine the relationship between population size and regional innovation and also influence from regional contingencies. We test hypotheses using data from official registers related to a population of Swedish municipalities (n=290) over a five year period. We adopted a lagged hierarchical regression technique with a population-averaged negative binomial estimation model where we controlled for the dependent variable at t-1. Results support a non-linear, inverted u-shape, relationship between critical mass and regional innovation. Further, results also suggest that the regional level of education support can mitigate the negative effects of a too large population.

Daniel Örtqvist is associate professor of entrepreneurship at Luleå University of Technology and a research fellow at the Centre for Inter-organizational Innovation Research (CiiR). His academic research mainly concerns the entrepreneurial identity, the establishment of new ventures and aspects of organized cooperation. He has published in a number of journals that include Journal of Management Studies, Strategic Organization, Long Range Planning, Scandinavian Journal of Management, Journal of Business Research, Journal of Business and Psychology and Journal of Applied Social Psychology.

Håkan Ylinenpää is professor in entrepreneurship at Luleå University of Technology and research director of Centre for Inter-organizational Innovation Research (CiiR). His research interest is focused on entrepreneurial innovation activities and strategies, especially in small and medium-sized enterprises, innovation system research, and knowledge management, and preferably involves research in close collaboration with practice and/or policy-makers in regional, national or international programs and projects. His scientific production involves numerous scientific journal articles, books/book chapters, and conference papers.

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Introduction

In a more knowledge-based society based on "flexible specialization" (Piore & Sabel 1984) and outsourcing, innovation and a dynamic development of companies and regions are normally understood as effects of networking and interaction. Actors possessing different and complementary knowledge and expertise are hence expected to produce more and more advanced innovations, and the more actors involved, the higher the potential is that the actual knowledge is both specialized and complementary. Since interaction due to the transaction costs collaboration involves (Coase 1937, Williamson 1981) benefits from actors being spatially, socially and culturally close, it has often been claimed that "proximity matters" (Maskell *et al* 1998). The blessings and dynamics emanating from the knowledge-based economy are therefore unevenly distributed in space since knowledge organisations as well as business innovation activities tend to concentrate to a few specific regions (Cooke *et al*. 2007). Such insights have in turn fertilized the emergence of theories and theoretical concepts such as "The K Society" (Andersson & Strömquist 1988), "clusters" (Porter 1998) and how actors belonging to "the creative class" tend to co-locate to specific innovative regions

(Florida 2005, 2007). Anne Saxenian in her study from 1994 of two such creative regions (the Bay area in Silicon Valley and the Route 128 area around Boston, US) confirmed this understanding, however by noting that the structures and modes for collaboration between actors involved in innovative activities were very different in the regions studied. Generally research in this stream has highlighted the importance of localized learning, and how social interaction based on cultural and spatial closeness facilitate trust, exchange and innovative activities in local or regional systems of interacting actors (cf. Maskell *et al*, 1998; Cooke *et al*, 2000; or Asheim & Coenen, 2006).

The understanding that size and proximity matters and that “large is beautiful” may however be challenged from different perspectives. Research in social psychology and group dynamics instead argue that there is an optimal size of actors for different kinds of assignments (see e.g. Wheelan 2009). The critical mass concept developed by Oliver, Marwell and others (Oliver, Marwell and Teixeria 1985, Oliver and Marwell 1988) highlights related phenomena pinpointing e.g. the need for a sufficient size of actors but where extending the number of actors beyond a certain limit (the critical mass) does not pay off.

In this paper we address the intriguing issue of whether there is an optimal size for local regions/municipalities for innovative activities, or if (as the mainstream literature seems to suggest) “larger is more beautiful”. We start by introducing our hypotheses related to regional size and its impact on regional innovation, and by introducing potential moderation effects from regional education support. We thereafter present the research methods underpinning the focal study and continue with presenting the results from empirical tests of the proposed hypotheses. We end with a discussion of the empirical findings and their implications for theory and practice related to regional innovation.

Towards a better understanding of size and critical mass

The size factor of organizations and regions has attracted significant research interest over the years, generating concepts such as economy of scale and economy of scope (Panzar & Willig, 1981; Cohen & Levin, 1989; Schumpeter, 1950). As already noted, most scholars advocate the view that larger organizations perform better due to their ability to contain and exploit internal resources and capabilities. E.F. Schumacher already in 1973 challenged this perspective by pointing towards the strengths of small organizations as compared to large corporations, and advocated the idea of "smallness within bigness": a specific form of decentralization. For a large organization to work, according to Schumacher (1999), it should behave as a group of related small organizations. Schumacher's work coincided with the growth of ecological concerns and the need for a more sustainable society.

Another argument towards a strict linear correlation may be found in the literature related to learning and creativity, where there is a longstanding insight that there is an optimal size of creative groups/teams for innovation and shared learning (see e.g. Wheelan 2009). On the one hand, it is logical to assume that the “absorptive capacity” (Cohen & Levinthal 1990) and the learning in a specific organization increases with the number of “nodes” or actors absorbing external input. To assume that such a relation is linear is however naïve on both an individual and an organizational level since the absorptive capacity of both individuals and organizations has its limits. After studying how more than 5,000 Swedish SMEs collaborate and how different collaborative modes may be related to innovation and growth, Westerberg and Ylinenpää (2009) and Ylinenpää and Westerberg (2004) hence indicated that having to many partners involved implies a less effective collaboration. The idea of an optimal size and composition of actors to facilitate sought-for effects of group dynamics such as creativity and innovation hence (even if the level of analyses is on the micro rather that on the meso or macro level) seems to question the taken-for-granted understanding that large always is beautiful. It also brings the issue of critical mass into focus.

The concept of critical mass emanates from physics and natural sciences, and may here according to AccessScience[1] be understood as the amount of fissile material (uranium-233, uranium-235, or plutonium-239) that supports a self-sustaining nuclear chain reaction. Transformed into the context of social sciences we may instead of uranium and plutonium talk about *actors* (individuals and/or organizations) possessing different kinds of resources and expertise which, when combined and interacted, ignite and support creative processes resulting in outputs such as innovative products and services. The critical mass concept developed by Oliver, Marwell and others (Oliver, Marwell and Teixeria 1985, Oliver and Marwell 1988) also addresses fundamental challenges involved in collective action such as how to handle efficacy and free-rider problems. Macy (1990) here notes that social learning serves as vehicle for actors to avoid self-defeating competition and instead involve in symbiotic behavior. Doloreux *et al.* (2007) advocate the view that regions in order to utilize their full innovative potential need a critical mass of knowledge, human capital and collaboration, and an innovation system's constituent elements, while Rosenfeld (2002) defines critical mass of clusters as their ability to attract specialized services, resources, and suppliers. Teräs (2008) discusses the concept of optimal size for high tech clusters and region, where the challenge is to achieve a minimum critical size of the high tech cluster but to avoid the problems related to large metropolitan high tech clusters such as traffic problems, housing costs, and the fragmentation of the cluster actors. Funk in a recent article (2010) demonstrates

[1] http://www.accessscience.com/index.aspx

how the concepts of critical mass and complexity may be used to analyse the emergence and further development of new products in different national settings and industries.

As already noted, critical mass for social scientists is a metaphorical concept borrowed from physics to refer to the idea that some threshold of participants or action has to be crossed before a social phenomena comes into existence (Oliver, Marwell, & Teixeira, 1985). Following Lundvall (1992), we consider regions as social systems consisting of a number of discrete elements (in our case individuals) and relationships between them. Our argument is that individuals are the carriers or containers of knowledge and information that in a knowledge-based economy to an increasing degree interact in order to develop innovations for a market.[2]

Increases in regional population size imply increases also in the human capital within the region which has been deemed important for the posture and direction of practical action and thereby also the evolutionary processes of a region (Cooke, Uranga & Etxebarria, 1997). More actors or individuals serving as containers for knowledge and information are in turn better able to provide a more appropriate milieu for innovation. Cooke, Uranga and Etxebarria (1997) argued that in dense settings firms are likely to have better contacts with: a) other firms (including customers, suppliers, partners) being part of formal or informal networks, b) knowledge-centres including universities, research institutes and technology transfer agencies, and c) governance structures consisting of private business associations, chambers of commerce, and other public agencies and government departments supporting businesses and innovation. Therefore we also expect that regions with a relative larger critical mass of actors will also exhibit a greater innovation output.

[2] Cf. the argument in research related to organizational learning that learning in organizations is based on and requires learning by individuals (e.g. Nordhaug 1993, Ylinenpää 1997).

As already indicated, such a general assumption may however on different grounds be challenged and in need for modification: that such a relation may be expected up to a certain level of size (critical mass) after which the relative effect of further increases will diminish the return on innovation. Following arguments from Nelson and Rosenberg (1993), regional innovation systems are normally not purposively designed but rather evolve and change over time. Therefore, the development of support structures for business and innovation may turn out to evolve as a complex and non-transparent support structure which imply different challenges, high transaction costs and that individuals in the region do not engage in innovative pursuits even if they are able to do so. Following this logic, studies on organizational settings have found size increases to be related to increased organizational complexity (see for instance Kahn *et al.*, 1964). As for organizations, an increasing population size of a region may invoke a higher need for differentiation and specialization at the expense of collaboration and coordination. Increased differentiation and specialization may in turn increase the fragmentation and complexity composed by different actors in a regional setting (cf. Teräs & Ylinenpää 2009), especially when considering that regional innovation systems are normally not purposively designed but emerge as results of evolutionary, bottom-up processes. Therefore, at a certain stage of a regional population growth, it may even be difficult to locate other firms to cooperate within formal or informal networks and it may due to organizational complexity be difficult to identify and get access to relevant and often specialized and differentiated knowledge-centres and governance structures. We therefore here assume that after a certain level of population size, the potential for an actor/individual to make use of the regional innovation system decreases as does the innovation output of the region. Our arguments are also in line with the social psychology or group dynamic perspective where individuals in large groups may reduce their performance due to greater risks for free-riding and for efficacy problems (Oliver & Marwell 1988). Research on the free-riding phenomenon has demonstrated e.g. how individual members in larger groups can benefit even without contributing to the group; a situation that seems relevant also in a regional setting. With increasing regional population size, individuals could choose alternative paths for engaging in renewal and development activities and thereby we could expect reductions in innovation with further increases in the regional population size indicating efficacy problems where individuals assume that the relative benefit for engaging in new innovation activities does not exceed their current perceived pay-offs.

Following this logic we assume that the relationship between regional size and regional innovation takes on the form of an inverted U-shaped curve, where initial increases in critical mass facilitates better conditions for regional innovation and where such increases reaches an optimum and thereafter have a negative influence on regional innovation. We therefore present the following hypothesis:

Hypothesis 1: The relationship between regional critical mass and regional innovation follows an inverted U-shaped curve.

The argument that regions housing a larger population may suffer from drawbacks related to a more complex system in terms of non-transparent specialization and fragmentation and higher levels of different transaction costs may however also be questioned. The “absorptive capacity” may hence be increased not only through extending the number of “absorbing actors” but also by developing such individuals’ own absorptive capacity. A classic way to achieve this is through developing individual skills and knowledge bases through higher education. In a study of more than 5,000 Swedish SMEs, Ylinenpää and Westerberg (2004) hence found that firms employing staff with higher education were more engaged in collaborative activities with partners outside their own company and outside the region in which they were located. At the same time, we also believe that in regions with a less developed education support it would be more difficult for the citizens to actually benefit from support structures and bridge necessary social actors to complete innovations. We therefore argue that the size and the level of regional education support can mitigate the challenges of complexity at too high levels of regional population size. In regions which have an education support structure where students perform higher grades it would be likely that the challenges related to population size are reduced or even diminishes. We hence assume that regions which can provide a relatively better education to students are also able to provide education about how the social/support system works and how to e.g. make use of regional resources. This would imply that regions where individuals have a formal background and training from e.g. Higher Educational Institutions such as universities would be better off to make use of the highly specialized and differentiated support structures and the more specialized structure of potential partnering companies inherent in e.g. larger metropolitan areas. We therefore present the following hypothesis:

Hypothesis 2: Regional level of education support moderates the relationship between regional critical mass and regional innovation. At low levels of education support the relationship follows an inverted U-shape and at high levels of education support the relationship takes a linear positive form.

Research Method

Data: We tested our model and hypotheses on a five year longitudinal data set on the complete population of 290 Swedish municipalities. We extracted all data from official registers such as Statistics Sweden and the Swedish Patent and Registration Office. In Sweden its 290 local municipalities are since 1971 the administrative arenas for local governance. As such, municipalities are the administrative regions of a country which has high relevance for policy-making interventions, which often is the core essence in definitions of regions**.**

Measures: All data has been collected from governmental registers. We measure regional innovation with the logarithm of the number of patent applications filed in each municipality as the dependent variable. Patent applications have been frequently used as a proxy for innovation and have been validated as a measure of regional innovation in several studies (see for instance Acs, Anselin, & Varga, 2002).

Independent variables are regional population size, operationalized by the yearly number of inhabitants in each Swedish municipality, and regional education support, operationalized as the average high school (upper secondary school) grades for each municipality. The independent variables are collected from Statistics Sweden and are standardized in the statistical tests following general guidelines for test of moderation. After standardizing the variables we estimated a non-linear term of regional population size and we calculated product terms of the expected moderation effect (regional education support) and the two terms of regional population size.

Analytic Procedures: We adopted a population-averaged negative binomial estimation model to test the hypotheses on the five year regional innovation panel data using hierarchical regression. We adopted the population-averaged negative binomial estimation model because our dependent variable was a count measure of the number of patent applications. Three regression models were estimated to test the hypotheses. The first model included a set of pertinent control variables. The second model added a set of independent variables (population critical mass and education support). The third model included a squared term of population critical mass to account for non-linearity. The fourth model included the interaction terms between population critical mass (both the main and squared terms) and education support.

Results

Overall, correlation coefficients between independent variables are within conventional limits not exceeding .60, implying that the threat of multi-collinearity is low (Cohen *et al.*, 2003). Average reported patent applications for the five years are 8.79 with a standard deviation of 31.25. However, the range of patent applications is between 0 and 531 patent applications. As such, it seems to be a reasonable variation in the levels at which regions develop new patent applications. A typical region had about 32 thousand inhabitants, with a standard deviation of 62 thousand inhabitants. The lowest number of inhabitants reported in a region was 2.5 thousand and the corresponding figure for the highest number of inhabitants was 829 thousand.

A hierarchical regression technique is employed for testing the hypothesized relationships. There is a one year lag between the modeled dependent variable and the control and independent variables. The first model thus includes a control for the lagged effect of regional innovation by insertion of the number of patent applications from the region at t-1 and control variables, also at t-1, such as regional population size and education support. The second model adds main relationships in form of regional population size and regional education support, the non-linear term of regional population size at t-1, and the interaction terms of regional education support at t-1. Table 1 presents the models and the results from the hierarchical regression tests. Overall, the variables show consistent directions and magnitudes in the models.

INSERT TABLE 1 ABOUT HERE

In the first model, the control for the lagged regional innovation turned out to be positive and significant ($\beta=.01^{***}$) and regional population size turned out to be positive and significant ($\beta=.88^{***}$). Regional education support, however, turned out to be non-significant ($\beta=.03$; $p>.05$). These effects are quite stable also over the second model.

The inclusion of main effects in the second model reveal that regional population size is positive and significant to regional innovation ($\beta=1.69^{***}$) and that the regional education support is not significant in relation to regional innovation ($\beta=.01$; $p>.05$). The inclusion of the non-linear term increases the explained variance and render a significant and negative term ($\beta=-.2^{***}$) which suggests that the relation between regional population size and regional innovation takes the form of an inverted U-shape in line with hypothesis 1. We plot the interaction in Figure 1 to further examine the nature of the relationship. The graph shows that the relation is curvilinear, and it clearly demonstrates that the relationship between regional population size and regional innovation follows an inverted U-shape relationship.

INSERT FIGURE 1 ABOUT HERE

The second model includes the interaction effect and reveals, as hypothesized, that the term of the squared regional population size and regional education support is significant to regional innovation (β=.07***). This implies, in support of hypothesis 2, that regional education support moderats the non-linear relationship between regional population size and regional innovation. Figure 2 depicts this relationship, which supports the anticipated inverted u-shaped relationship between regional population size and regional innovation in regions with a low (i.e., -1 SD) regional education support and the positive linear relationship between regional population size and regional innovation in regions with a high (i.e., +1 SD) regional education support.

INSERT FIGURE 2 ABOUT HERE

In sum, our results show that population size is positively related to regional innovation but that, when controlling for non-linearity, this effect turns out to be diminished or wiped out at a certain population level. This implies that increases in population critical mass is positive for regional innovation up to a point, but after that further increases actually contributes to reductions in regional innovation. Further, we also tested the hypothesis that a regions education support positively influences regional innovation outcomes. Empirical results were not conclusive for the main effect but clearly demonstrated that the interaction term of population critical mass and education support influenced regional innovation. Interpreting the moderation effect for the real range of the dataset we find that the non-linear effect of population critical mass on regional innovation is dependent on the level of education support. At low levels of education support we find a strong non-linear (so called inverted u-shape relation) effect between population critical mass and regional innovation. However, at high levels of education support the effect seem more linear and positive between population critical mass and regional innovation. This implies that educational support can mitigate the negative effects of a too large population.

Discussion

The present study combines perspectives of regional population size and regional education support to show how they jointly influence regional innovation. In brief, this study advances the understanding of the influence of regional population size on regional innovation by hypothesizing and empirically supporting that the relationship is non-linear and follows the shape of an inverted U-curve. This implies that regions with too small and too large populations have worse potential of fostering innovation activities and outcomes relative regions with a balanced size of the population. Further, this study also demonstrates how potential weaknesses of a too large regional population can be overcome by developing a regional education support system. The present theorizing joins arguments in existing regional literature and advances the understanding for the complexity in what determines regional innovation.

Despite the mentioned contributions, the study is not exempt from limitations. The study adopted a lagged design to make sure of causality and to control for lagged effects from the dependent variable. Still, the true time for population size and education support to manifest in regional innovation is difficult to assess. Future studies could gain from further testing of when the influence from regional characteristics such as population size influences regional innovation.

Determining cause and effect in social science is a classic intriguing challenge. We have here targeted the role of regional (local municipality) population size on a conventional proxy used to indicate innovative activities in a region. Although such an approach here generates interesting findings, it also challenges future research to consider also other potential dependent and independent variables. Measuring innovative output as the number of patents registered in a region is a classic but still not an ideal proxy for regional innovativeness. Further research in the field would certainly benefit from utilizing also other measures of regional innovation. Referring to potential explanations behind variations in regional innovation, future research could investigate e.g. the impact from the degree of internationalization and export in existing regional industry and business, R&D intensity, local entrepreneurship in terms of the density of self-employed or the number of new start-ups, measures of regional attractivity depicting e.g. number of in-migrants or people belonging to Florida's "creative class", or the impact from different levels and directions of higher education.

Another potential limitation of this study is that regions are sampled from municipalities within one country. It is possible that the logic for how innovation occurs is different in other cultural contexts and in other definitions of regions. By this we would like to argue that care should be taken before findings are generalized to other contexts and settings. However, future studies need to determine whether the findings are possible to generalize to other contextual settings and where the boundaries for the present results lie. One interesting design would be to adopt multi-level modeling and test if regional characteristics influencing regional innovation are related to the cultural context in which they are performed.

A final intriguing issue related to this discussion is also to what degree lack of (local or regional) critical mass may be compensated by relations and interaction utilizing modern information and communication technologies (ICT). Here concepts such as “open innovation” (Chesbrough 2003, 2007) advocate the need for borderless interaction on a more or less global arena in order to be able to explore and exploit emerging innovative opportunities; thus redefining the arena on which actors constituting critical mass may emerge. An intriguing issue for further research would therefore be to investigate to what degree use of ICT for exchange and collaboration related to innovation can compensate for shortcomings in a local milieu.

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Tables and Figures Follows

TABLE 1
Influences on Patent Applications

	Model 1		Model 2	
	Coef.	Std. Err.	Coef.	Std. Err.
Previous regional innovation	.01***	(.01)	.01***	(.01)
Regional population size	.88***	(.08)	1.69***	(.13)
Regional population size (squared)			-.21***	(.02)
Regional education support	.03	(.04)	.01	(.05)
Two-way Interactions				
Regional population size * Regional education support			-.12	(.14)
Regional population size (squared) * Regional education support			.07***	(.02)
Constant	1.43***	(.07)	1.43***	(.07)
Chi-square	(3)562.69***		(6)270.71***	

*p < 0.05; p** < 0.01; ***p < 0.001. Two-tailed tests.

FIGURE 1
Critical Mass and Regional Innovation

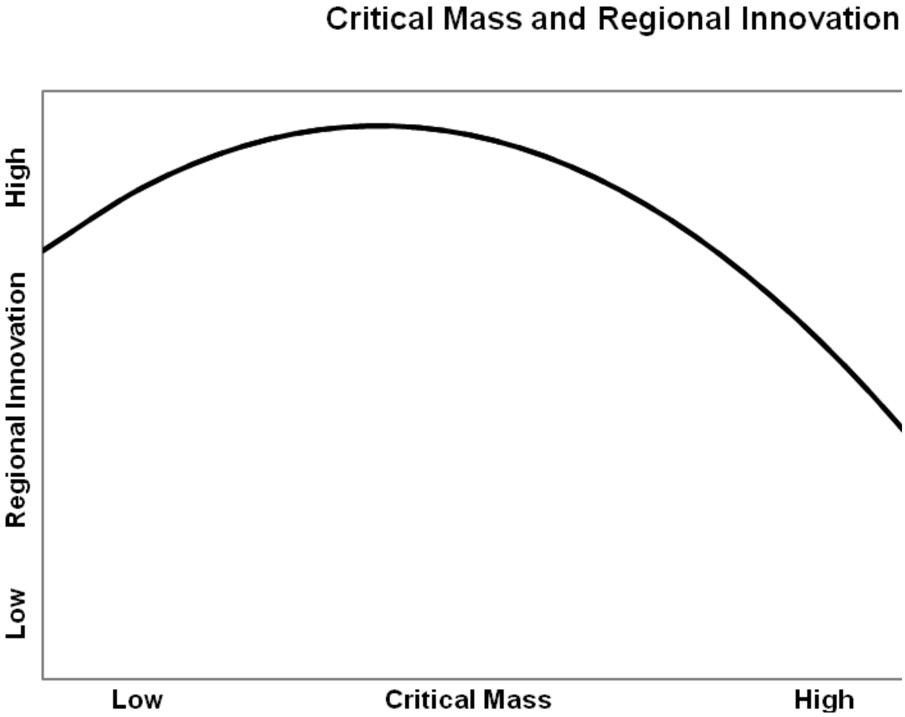

FIGURE 2
Critical Mass and Education on Regional Innovation