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Inventive and innovative activity over time and geographical space: the case of Sweden

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Abstract

Two ‘stylized facts’ about innovations form the underlying motivation for this paper. First, various studies have found that innovations tend to be geographically concentrated. A number of theoretical propositions have been put forward to explain this phenomenon, most of them related to agglomeration economies. Secondly, innovation data based on patent counts indicate that most patents have very low economic value. It has also successfully been shown that ‘quality-adjusting’ patent data (by means of e.g. citations received from later patents) bring them a great deal closer to the innovation concept. Nonetheless, in the existing literature are such quality-adjustments entirely lacking geographical scope. Given that the value distribution of innovations is highly skewed, s confirmed by quality-adjustment, we expect quality-adjustment to make innovations even more unevenly geographically distributed. This paper examines whether quality-adjusted patents indeed are even more unevenly distributed across regions. This is done by comparing quality-adjusted patents using factor analysis with unadjusted patent counts. Contrary to expectations, taking quality into account seems to reduce innovation concentration. Therefore, basing measures on geographical innovation only using patent counts without taking quality into account, may therefore overstate the geographical concentration of innovation.

"Inventive and innovative activity over time and geographical space: the case of Sweden"

Olof Ejermo[1][2]

Abstract

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This paper examines whether quality-adjusted patents indeed are even more unevenly distributed across regions. This is done by comparing quality-adjusted patents using factor analysis with unadjusted patent counts.

Contrary to expectations, taking quality into account seems to reduce innovation concentration. Therefore, basing measures on geographical innovation only using patent counts without taking quality into account, may therefore overstate the geographical concentration of innovation.

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1 Introduction

This paper brings together two different types of literature. One has used different innovation indicators, including patent data, to examine the geography of innovation. The second strand has used adjustments to patents in order to make them more representative of innovation. Most patents are of very little economic value for several of reasons. For instance, a patent may not, as the inventor may have originally intended, result in economic benefits. A patent may be taken out for strategic rather than economic reason in order to block competitors, etc (Griliches, 1990). For this reason a set of 'quality-adjusters' are beginning to form accepted ways of making patents more representative of innovation. The literature on the geography of innovation shows that innovations are remarkably concentrated in geographical space – much more so than population or production. Agglomeration economics is usually portrayed as having a high explanatory power behind this finding (Ejermo, 2005). Explanations encompass localization economies, a concept which rests on industry specialization. These comprise cumulative learning effects; the presence of specialized suppliers, and economies of scale, all of which lead to lower costs for industries locating in vicinity of each other (Marshall, 1920; Arrow, 1962; Romer, 1986). Urbanization economies on the other hand, stresses the importance of variety in the set of goods and skills available locally in order for firms to be innovative (Ohlin, 1933; Hoover, 1937; Jacobs, 1969).

The two strands (quality-adjustment of innovation indicators and geography of innovation) have hitherto not been combined. We simply do not know the geographical properties of patents once adjusted for quality. Therefore, the aim of this paper is to examine the geographical distribution of patent counts, before and after quality-adjustment. The paper is organized as follows. In section 2 the most common innovation indicators are summarized and explained. Subsection (2.1) report on studies that have used patents to indicate innovation in geographical space and (2.2) on the literature on quality-adjustments of patents. Section 3 describes the patent material at hand and analyzes the material. Section 4 concludes.

2 Innovation indicators

The measurement of innovation is not uncontroversial. Most researchers agree that a complex thing such as innovation is difficult to capture by a single measure. However, certain measures may be more general than others. Besides, it is important for many uses to be able to characterize something as 'innovative' or not. Kleinknecht (2002), and Smith (2004) discuss several aspects of innovation indicators. The most common innovation indicators include R&D, patents, and two categories labeled by Smith (2004) as innovation counts – the object approach, and surveys – the subject approach. Among innovation counts we find expert appraisals compiled by SPRU for the UK for the period 1945-1983 reported on in Pavitt et al. (1987), 'important' innovations as assessed by the US Small Business Administration (SBA) (see e.g. Feldman and Audretsch, 1999) which is based on trade journals. Related are *literature based innovation indicators* that have been collected for the Netherlands (Kleinknecht et al., 2002), for Italy (Santarelli and Piergiovanni, 1996) and recently for Finland (Saarinen, 2005).

2.1 Patents as indicators of geographical innovation

Patents are also good at indicating geographical location compared with other indicators, since the address of the inventor(s) is given. Records are also highly available (since this is one of the pillars of the patent system) and time-series are available up to the level of date of application. Moreover, certain characteristics of patents can be used to check for ‘quality’. Several papers also use patent data to examine innovations in geographical space. A few years back examination of the concept ‘localized knowledge spillovers’, i.e. how and if public or private innovative activities (usually R&D) is spatially bounded, was highly fashionable. This literature tends to find that this is in fact the case for other innovation indicators (e.g. Acs et al., 1992; Acs et al., 1994; Audretsch and Feldman, 1996a; Audretsch and Feldman, 1996b; as well as those using patent data (e.g. Jaffe, 1989; Paci and Usai, 1999). Acs et al. (2002) have found that different innovation indicators, are highly correlated for U.S. Metropolitan Statistical Areas (MSAs).[3]
Also, among patent studies we find papers that use *citations* to proxy for knowledge flows (Jaffe et al., 1993; Maurseth and Verspagen, 2002; Fischer and Varga, 2003). These studies show that citations between two patents tend to be more frequent when the two are closely located geographically.[4]

2.2 Quality-adjustment of patents (& regions)

Patent counts represent a kind of input into innovation processes. The invention represented by the patent does not automatically transform into innovations or growth. It is well known (e.g. Griliches, 1990) that the value of granted patents is skewed, so that only a limited number create large economic value, while the majority practically does not contribute to any value creation whatsoever. Later studies have shown that patent citations and other related measures contribute to clarification of the value of individual patent applications. The functional and legal meaning of a patent citation (“prior art”) is that it delimits the technological scope of the new patent. The citation of earlier patents thus communicates that the patent does not embody the technological content of the cited patent. Studies have used forward citations to ‘weigh’ the importance of patents, the main idea being that more valuable patent are more widely cited. This information can be complemented by other adjusters such as whether the patent has been renewed, degree of generality, originality and ‘radicalness’. For data from the European Patent Office (EPO), the number of countries where the patent has been taken out, ‘family size’, whether the patent was opposed, and upheld, in court can be used. The validity of these measures have been shown by *indirect* studies relating the measures to productivity, expert appraisal of innovations, and stock market value of companies with patents in their portfolio (Trajtenberg, 1990; Lerner, 1994; Harhoff et al., 1999; Jaffe and Trajtenberg, 2002; Harhoff et al., 2003; Lanjouw and Schankerman, 2004; Hall et al., 2005; Hall and Trajtenberg, 2005; Dahlin and Behrens, 2005). Also, questionnaires sent to inventors and managers about the values of individual patents give direct validation for quality-adjustment methods (Gambardella et al., 2005).

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[3] Breschi and Lissoni (2001a,b) give excellent critique on this literature.

[4] Recently, the methodology used by Jaffe et al. (1993) has been debated by Thompson and Fox-Kean (2005) and Henderson et al. (2005).

Although Jaffe et al. (1993) examined geographical properties of one patenting indicator (citations), they examined how it related to knowledge flows across geographical space and did not use it as a quality-adjuster. The following section describes the datamaterial which uses Swedish regions as a case study for examining the geographical properties of quality-adjusted patent data.

3 The patent data

The following data builds on previous work by Ejermo (2004) to allocate EPO data to Swedish regions. The present version of the database has undergone further quality checks.[5] EPO patents are more likely to be more valuable than national patents for the obvious reason that in order to protect the patent in more than one country, the applicant has considered the extra cost of applying through the EPO worthwhile. A patent is in this paper considered (at least partially) Swedish if the creative act of producing the patent came from the mind of a person registered with a Swedish address.[6] Fractional counting was used, meaning that when a patent for example was invented by three inventors, whereof two were registered with Swedish addresses, 1/3 of the patent was allocated to each of the residential regions of the Swedish inventors (totaling 2/3 of the patent). Patent applications, family size and opposition incidence data comes from the EPO bulletin and information about whether they were granted and citations are from OECD (2005). The citations data from OECD (2005) used are not only from other EPO patents, but also from patents granted via the internationally harmonized PCT-process (these follow the same citation praxis as EPO). For the present paper, only granted patents were selected when calculating quality-weighed counts. For reasons of bias and truncation, the subset of Swedish EPO patents applied for in 1982-1999 are used for analysis. Although EPO started to grant patents in 1978, data clearly shows a sharp increase in the first few years. Only from 1982 onwards does the trend become more stable. After 1999, most patents have not yet received all their citations.

Five indicators are calculated for Swedish regions: number of grants, forward-citation weighed grants, backward-citation weighed grants, family size and opposition incidence. The rationale for the use of these indicators is that patents that receive Forward citations have been useful for the development of latter patents. Backward citations show the extent of use of earlier patents, which may indicate that more effort has been put down on the patent. A higher Family size shows that the applicant finds it worth the filing costs of extending the patent to additional countries and thus suggestive of value. Opposition incidence indicates that other agents find it worthwhile to undergo costly judicial process in order to invalidate a patent. The number of grants is the simplest of our measure.[7] The sum of granted patents in a region is written:

$$NGRANTS_{tr} = \sum_{i} NGRANTS_{tr,i} \qquad (1)$$

[5] For instance, two versions of postal registers from 1993 and 2004 respectively have been used to map inventors' addresses to regions.

[6] This leads to the unavoidable consequence that inventors of non-Swedish nationality may appear under a Swedish address.

[7] The geographical distribution of *applications* was nearly identical.

where i denotes an individual granted fraction (as defined above). Different quality-adjusters presumably form higher quality-level, though quality differences between them cannot easily be determined. The following formula applies to the method of obtaining citation-weighed grants $FCIT_{tr}$:

$$FCIT_{tr} = \sum_i FCIT_{tr,i} \cdot NGRANTS_{tr,i}, \qquad (2)$$

where $FCIT_{tr,i}$ denotes the number of (forward) citations received by later patents. Analogously we have $BCIT_{tr}$ for backward citations made to earlier patents. We also write:

$$FAMSIZE_{tr} = \sum_i FAMSIZE_{tr,i} \cdot NGRANTS_{tr,i} \qquad (3)$$

with $FAMSIZE_{tr,i}$ showing the number of countries ('designated states') in which the patent was applied for. The incidence of opposition gives us :

$$OPPOSITION_{tr} = \sum_i OPPOSITION_{tr,i} \cdot NGRANTS_{tr,i}, \qquad (4)$$

where $OPPOSITION_{tr,i}$ takes the value 1 if there are one or more opponents in court, and 0 otherwise. The variables can also be examined as occurrences per granted patent in which case we label them as $FCITPERGRANT_{tr}$, $BCITPERGRANT_{tr}$, $FAMSIZEPERGRANT_{tr}$ and $OPPERGRANT_{tr}$.

3.1 Swedish patenting and associated indicators over time

The development of patenting in Sweden over time is shown in Figure 1. Note that the year of application is consistently used, also for the granted patents. The figure shows a substantial increase in applications until 2001. The number of grants started to fall after 1997, and the number of applications seems to have fallen in 2002. This data reveals that the grant-application ratio (right axis) starts to fall rather dramatically after 1995. The development seems to follow the notion of 'patent explosion' (Hall, 2005). Figure 1 also indicates that the quality of applications may have fallen over time, since smaller shares of applications are granted over time.

Figure 1. Swedish patent applications and grants to the EPO 1978-2005.

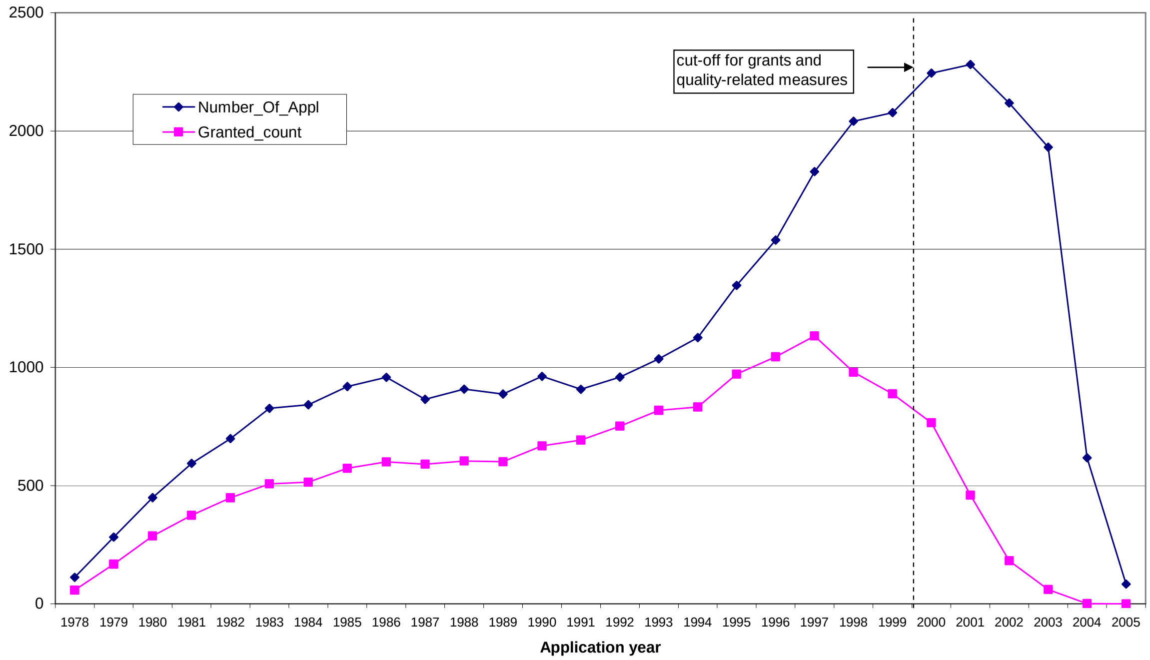


Figure 2-4 give somewhat mixed evidence as regards the quality of granted patents. The average numbers of forward and backward citations to each patent fall consistently over almost the entire period. Moreover, opposition incidence falls slowly over time, also suggestive of lower quality. On the other hand, family size per patent rises. An important reason for this is that the number of EPO-members increased from 9 in 1978 to 20 in 2000 and 31 in 2005! This means that the attractiveness of filing patents at the EPO has probably increased over time, since the increased number of members should yield some increasing returns to patent. Moreover, the number of citations to an older patent should increase because there are simply more countries gaining membership to the system. Any comparison over time therefore necessitates controlling for time effects.

Figure 2. Forward and backward citations per granted patent.

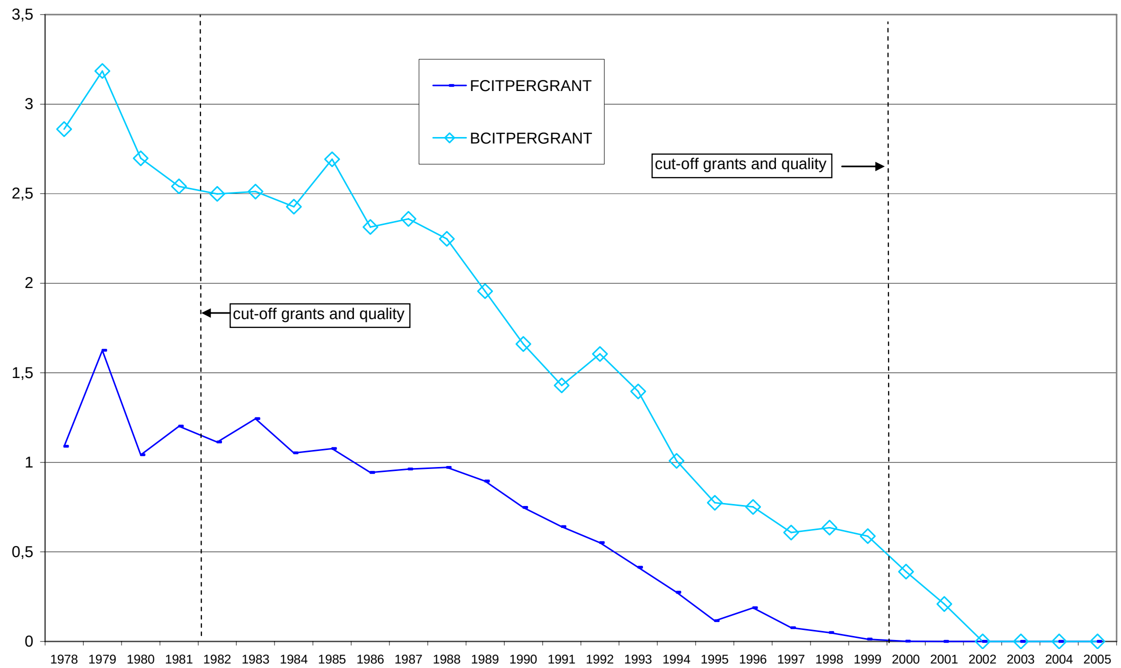


Figure 3. Average opposition incidence for granted patents.

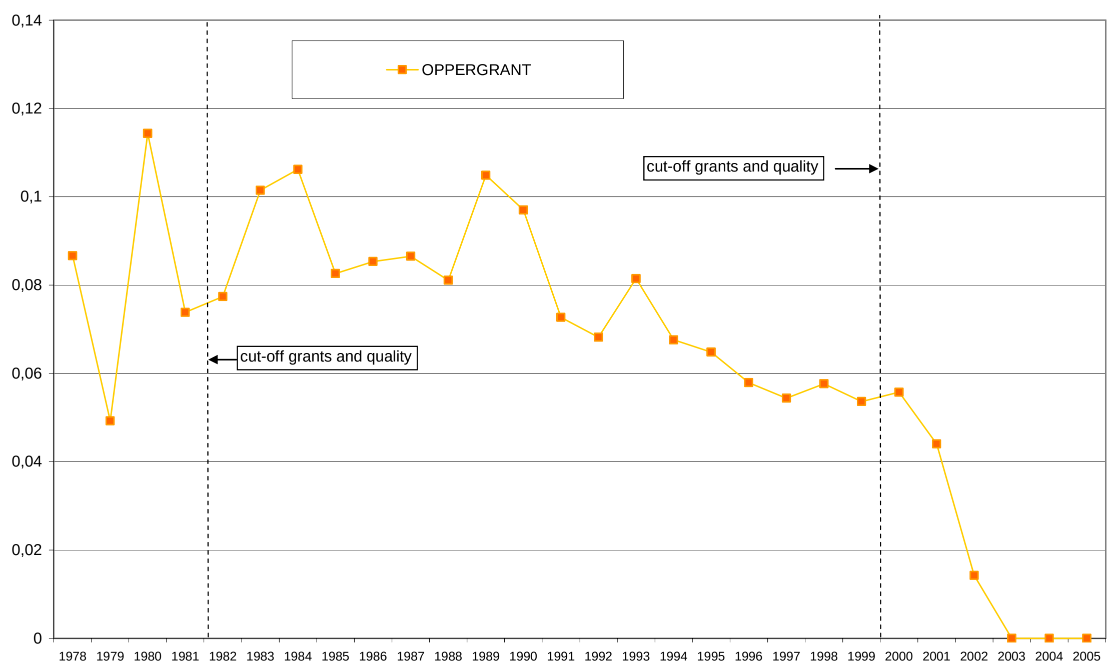
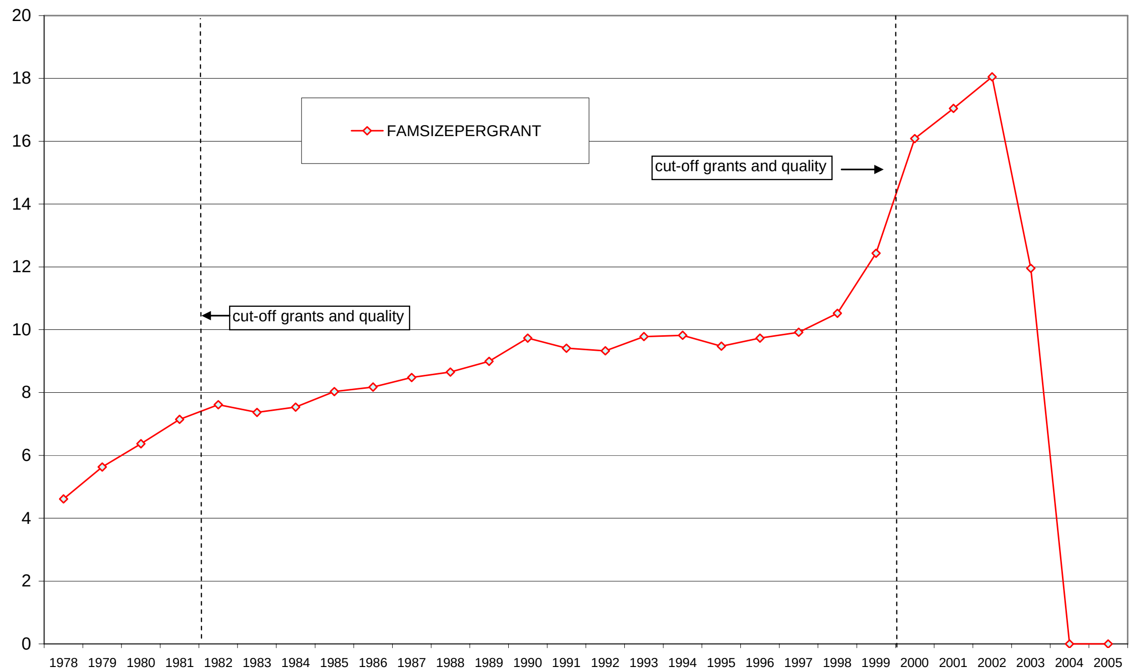


Figure 4. Family-size per granted patent.



3.2 An index of regional innovation

Following Lanjouw and Schankerman (2004) and others[8], we can use factor analysis on our patent quality indicators to construct an "index" which we will call regional innovation based on our quality-adjusters. Factor analysis is based on the assumption that one or more latent factors help explain a common variance among explanatory variables. Our base specification is written:

$$y_{ki} = \mu_k + \beta \cdot year_i + u_{ki}, \tag{5}$$

where y_{ki} indicates the value of the *k*rh indicator (*FCIT, BCIT, FAMSIZE* and *OPPOSITION)* for the *i*th patent (in logs)[9], μ_k are constants for each of the factors, β is an estimated coefficient from regression and *year* is simply the year to control for time as outlined above. Each stochastic component u_{ki} is defined as $u_{ki} = \lambda_k q_i + \varepsilon_{ki}$, q_i being the common factor, λ_k the factor loading and ε_{ki} the error term. The q_i terms are normalized to have zero mean and unit variance. The error terms ε form a covariance matrix $\mathbf{\Lambda}$ whose generic element is $[\lambda_l \lambda_m + \sigma_{lm}]$, where *l,m=1,2,3,4* and σ_{lm} is the covariance between the ε terms. This covariance structure is used to delineate the common factor(s). The theoretical covariance matrix is

[8] Gambardella et al. (2005) and Mariani and Romanelli (2006) are also two recent papers employing this methodology to patent data.

[9] Since some regions have zero values for some of the quality-adjusters the value $\log(1+X)$ was used.

$$\mathbf{\Lambda} = E(\mathbf{y}\mathbf{y}') = \boldsymbol{\lambda}\boldsymbol{\lambda}' + \mathbf{\Phi} \quad (6)$$

, where $\mathbf{y}$ is the vector of the indicators, demeaned and $\mathbf{\Phi} = E(\boldsymbol{\varepsilon}\boldsymbol{\varepsilon}')$, with $\boldsymbol{\varepsilon}$ being the vector of error terms. The posterior mean and variance of the latent variable conditional on observed indicators are

$$E(q|\mathbf{y}) = \boldsymbol{\lambda}'\mathbf{\Lambda}^{-1}\mathbf{y}, \quad (7)$$

$$\mathrm{Var}(q|\mathbf{y}) = 1 - \boldsymbol{\lambda}'\mathbf{\Lambda}^{-1}\boldsymbol{\lambda}. \quad (8)$$

The matrix $\mathbf{\Lambda}$ is not known and needs to be estimated. This is done by using communality estimates, initial estimates based on the correlation matrix of the indicators. While in principal component analysis the diagonal elements are also based on the correlation matrix they are in factor analysis based on *communalities* between the factors, i.e. the variance which the factors have in common. It is commonplace to use the squared multiple correlation of the factor in a regression on all the other factors to form initial estimate of these values (Marcoulides and Hershberger, 1997). Using our 72 regions and also including a foreign region[10] over the time period 1982-1999 yields 1314 observations. The correlation matrix with the initial communality estimates are given in Table 1.

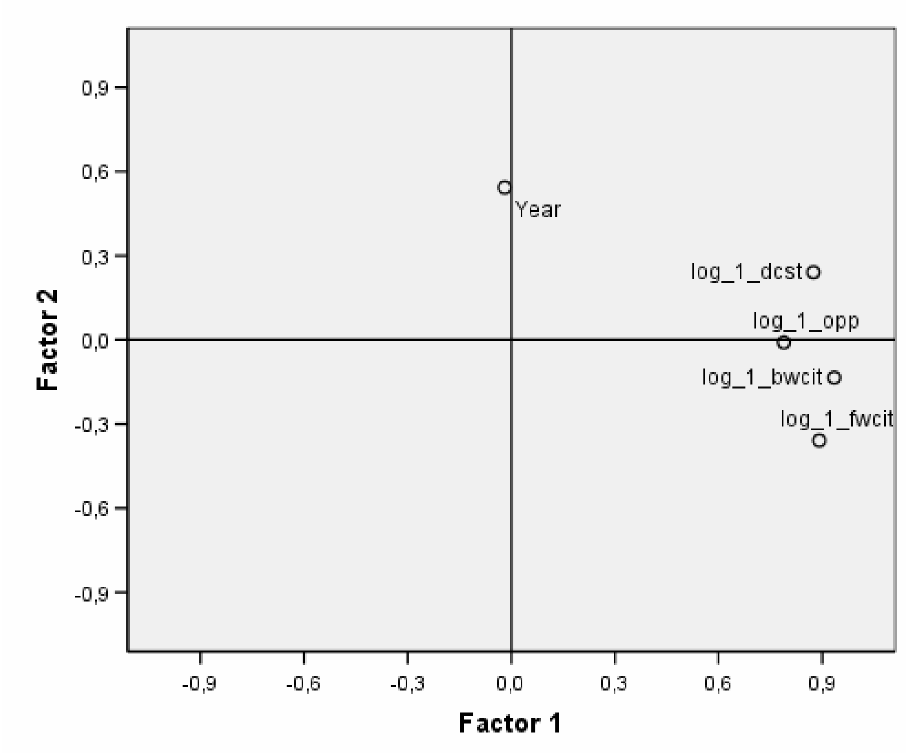
Table 1. Correlation matrix of variables, except for the diagonal elements which show the initial communality estimates.

	YEAR	*FCIT*	*BCIT*	*FAMSIZE*	*OPPOSITION*
YEAR	0.188				
FCIT	-0.208	0.802			
BCIT	-0.115	0.868	0.851		
FAMSIZE	0.110	0.676	0.816	0.720	
OPPOSITION	0.006	0.743	0.721	0.671	0.614

This matrix is used to derive initial estimates, which are used in an iterative process until convergence is obtained. In factor analysis the choice is in how many of the factors to use. A common criteria is to use the factors whose eigenvalues exceed one (the Kaiser-criterion). The method results in two factors being used, together accounting for nearly 87 per cent of the initial variance of the five variables. Plotting the rotated two-factor solution using the varimax method with Kaiser normalization gives us Figure 1.

[10] This region are patent shares accruing to non-Swedish inventors which co-operate with Swedish ones.

Figure 5. Factor Plot in Rotated Factor Space.

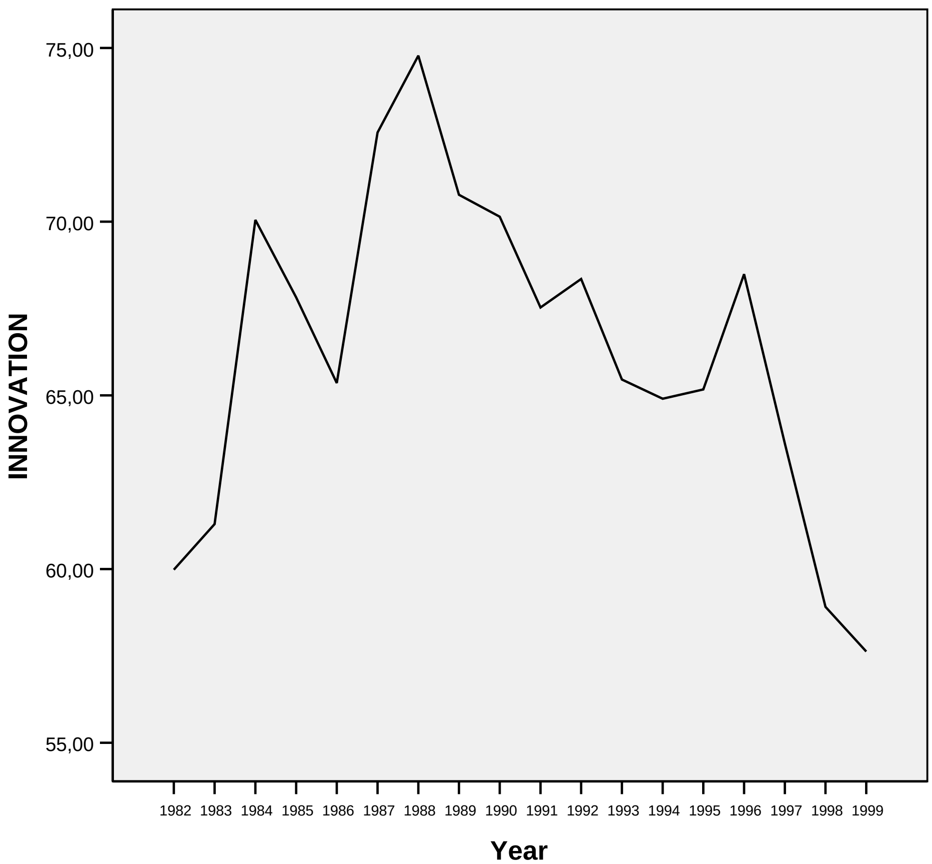


The interpretation is fairly straight-forward: the variable "Year" is almost entirely accounted for by Factor 2. The quality indicators contribute with positive values for Factor 1, although they also contribute to some extent to Factor 2. Hence, Factor 2 is interpreted to represent "TIME" and Factor 1 to represent "INNOVATION".[11] We now do two things with this latter estimated factor. First, we are interested in getting an overall picture of the development of INNOVATION over time. This gives us a way of summarizing

[11] By construction, the factors are on average zero. To facilitate computation (especially the Herfindahl index used below) the index is transformed as $INNOVATION_r = FACTOR1_r + \min(FACTOR1_r)$. This ensures that $INNOVATION_r \geq 0$.

Figure 2-Figure 4 discussed above. Secondly, we are interested in examining the changing distribution of INNOVATION over Swedish regions over time and compare that result with the distribution of raw patent counts (granted patents). Figure 6 plots the development over time of the sum of INNOVATION values across regions. It shows a rather uneven development. An initial low innovation level in 1982 is followed by an unevenly rising level until the series peaks in 1988. The period 1989-1999 is characterized by a gradually lower innovation level, except for small peaks in 1992 and 1996.

Figure 6. Development of innovation over time.

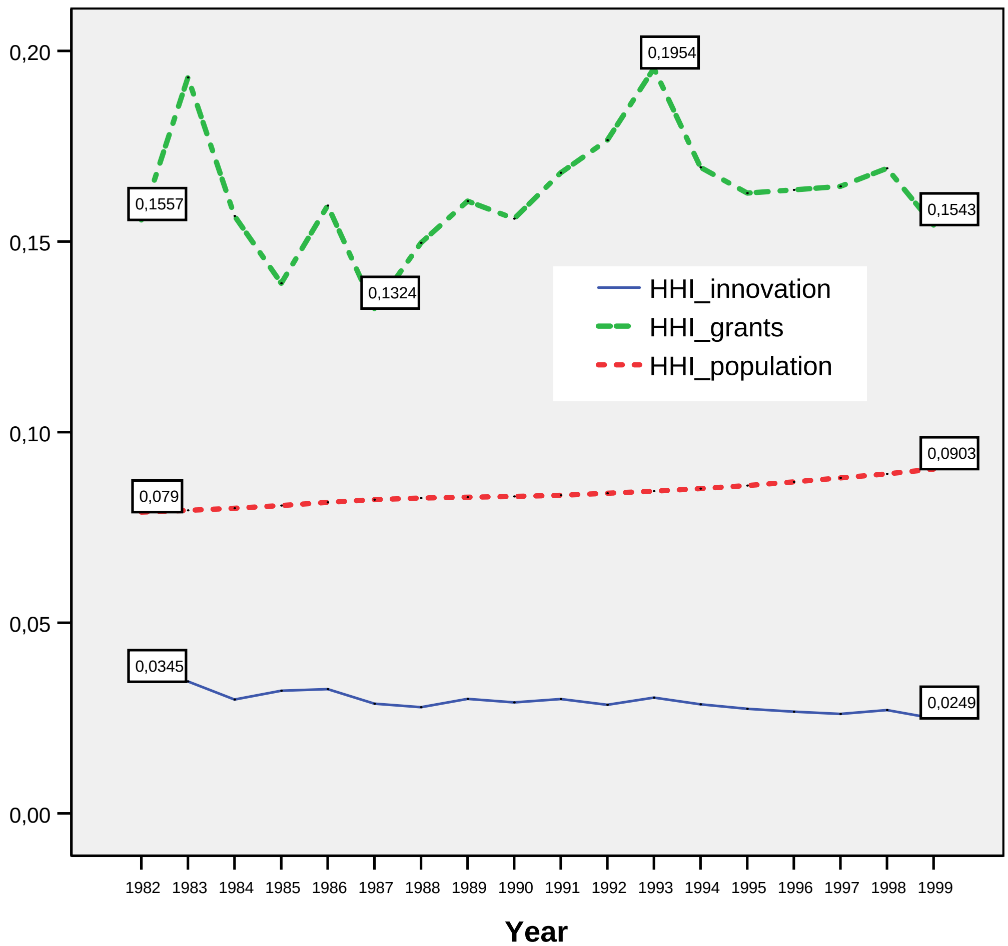


We now examine the geographical distribution over time. Figure 7 shows the Hirschmann-Herfindahl Index (HHI) of INNOVATION, NGRANTS and population from Statistics Sweden.[12] The graph reveals that INNOVATION has had a gradual decline in concentration over Swedish regions. The line for NGRANTS shows a markedly higher concentration than for innovation over the whole period. At the same time its concentration shows no consistent trend, though there is a great deal of variation over the time period, with a trough in 1987 and a peak occurring in 1993. This means that

[12] The index for period *t* is calculated as $HHI_t = \sum s_{rt}^2$ where s_{rt} is the share of NGRANTS or the share of INNOVATION in region *r*.

innovation, as calculated using the data from our factor analysis, may in fact have become more geographically dispersed over time. At the same time it should come as a no surprise that population has become consistently and increasingly concentrated over time. This means that also "innovation per capita" is becoming less, not more, concentrated. Slightly differently put, an increasing share of patents in more urbanized areas have lower quality.

Figure 7. Hirschmann-Herfidahl Indices for INNOVATION and NGRANTS.



4 Conclusions

Using forward citations, backward citations, family size and opposition incidence as quality-adjusters of patents this paper forms a common factor labeled *INNOVATION* for the period 1982-1999. While *INNOVATION* in itself seemed to become higher during the 1980s, the factor indicates a loss of quality in the 1990s. The factor also suggests that Swedish regional innovation is become less, not more, geographically concentrated, over time, especially in per capita terms due to ongoing urbanization in the period. This stands in contrast to the use of the normal innovation indicator patent grants. Contrary to expectations, taking quality into account therefore seems to reduce innovation concentration. Therefore, basing measures on geographical innovation only patent counts without taking quality into account may therefore overstate the geographical concentration of innovation.

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