A Decade after Hicks and Katz: Interdisciplinary Research Re-Examined

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Abstract
Following the innovative method from the SPRU paper by Hicks and Katz in 1996 we investigated different aspects of the interdisciplinary trends in Europe. The paper uses ISI data covering the period from 1982–2003. The trend towards multi- and interdisciplinarity in the natural, medical and technological sciences is growing stronger over time. In our analysis we use number of publications and citations in different areas of research, countries, sectors and universities. This gives an overview of interdiscplinarity as a phenomenon. Detailed Swedish data is used as a case study. The paper concludes with a short discussion on interdisciplinarity and research level. (April 18, 2005)

Introduction
In their innovative article from 1996, Hicks and Katz (then at SPRU) tested hypotheses that had been put forward by the Gibbons group (1994) and John Ziman (1994). Ten years ago many observers believed that interdisciplinary or even transdisciplinary research would become significant for nearly all types of research. It is no coincidence that the Gibbons book was financed by one of the Swedish agencies for boundary-spanning research, the FRN (The Swedish Council for Co-ordination and Planning of Research). That agency, politicians and officials from the Ministry of Education and Science supported ideas of a transdisciplinary transition during the 1990s.[1] In Sweden, when the liberal government came to power in 1991, several radical ideas on how to transform research in the direction of applicability and usability for industrial and political ends were brought to the political arena. Interdisciplinarity was among the ideas supported by the new research foundations created at that time. The regulations for these foundations stated that they should fund interdisciplinary research programs.[2]

Since then, interdisciplinary research (IDR) is frequently included in Swedish governmental bills and investigations (Sandström 2005). Also, governmental directives to the research councils state that they should arrange for and give adequate support to IDR. The number of articles debating IDR issues increased during the 1990s, but since 2002 interest seems to be decreasing somewhat.[3] Approximately 1% of the articles in Web of Science (WoS) use IDR terms (multi- inter-, transdisciplinary) in title or abstract. Between 1991 and 2005, the number of these articles increased by 250% while the total number of articles during the same period increased by only 40%. The greatest numbers of articles are found in the subject areas of clinical medicine (surgery, public health, rehabilitation etc.), environmental science and educational sciences.[4]

Is there an increasing trend towards interdisciplinarity in modern science? Our paper investigates this question, following the outline below:

First, assuming that the proposed Hicks and Katz method of using multi-assigned journals is an interesting solution to the problem of how to measure interdisciplinary research, we will discuss the guidelines and replicate their study using data from Thomson/ISI Web of Science.[5] Also, we will investigate the frequency of interdisciplinary publications after the period covered in the Hicks and Katz paper (i.e. 1991–2003).

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[1] The history of Swedish policies for interdisciplinarity is analysed in Sandström et al. (2005).
[2] Benner & Sandström (2000).
[3] Cf. Sandström et al. (2005).
[4] Source WoS, 1372 articles in 2002–2003, see Sandström et al (2005), cf. Braun & Schubert (2003).
[5] Certain data included herein are derived from the Web of Science prepared by Thomson Scientific Inc. (ISI), Philadelphia, Pennsylvania, USA.

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Secondly, regarding interdisciplinary publications, we perform a detailed analysis of Swedish universities by comparing universities with a set of different faculty areas of science.
Thirdly, we summarise our reflections on possible flaws in the Hicks and Katz method.

Methods

Hicks and Katz (1996) proposed a classification scheme using multi-assigned journals in the ISI database. For their purpose, they created four different classes of research, three of which were defined as multi- or interdisciplinary (the categorisation is further explained in Figure 1).

A. Single-field journals	Biomedicine, Biology, Physics etc.
B. Cross-field journals	
B.1. Interfield	IFLI (life), IFNA (natural), IFENMA (eng &materials)
B.2. Interdisciplinary	LIENMA (life+eng&materials), LINA (life+natural), NAENMA (natural+eng&materials)
B.3. Multidisciplinary	MUL (life+natural+eng&materials)

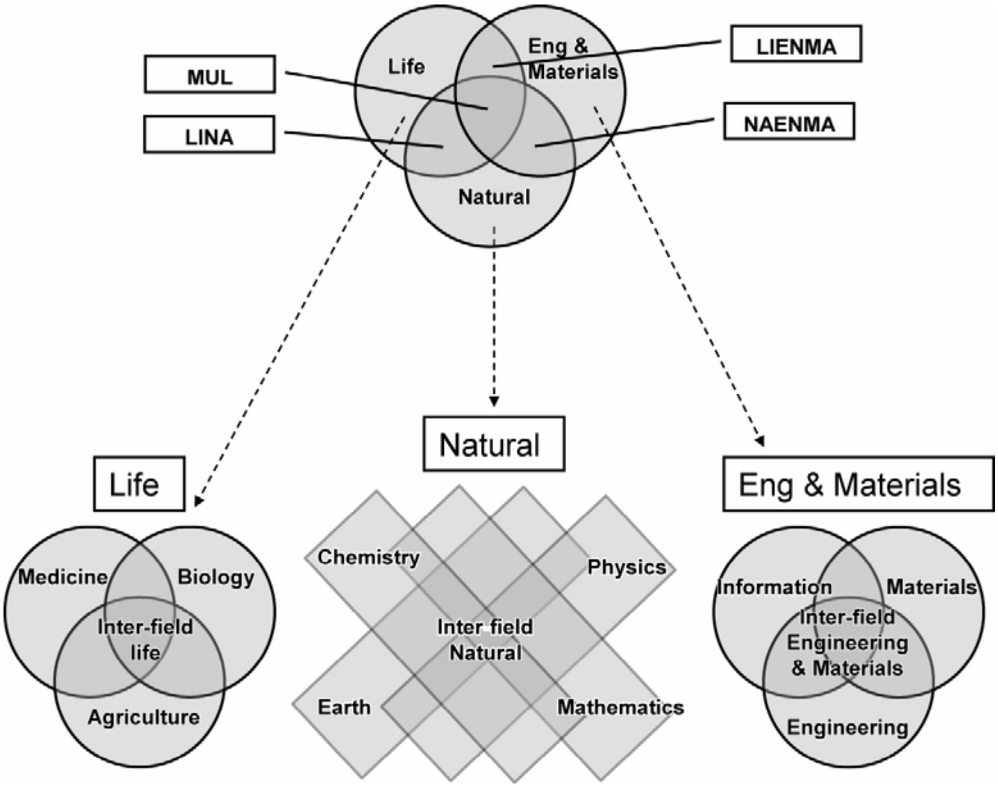

Figure 1. SPRU-method for classification of interdisciplinary journals
(with minor corrections to Katz & Hicks 1997).

Figure 1 illustrates the logic behind the classification that creates cross-field areas. Articles are classified into scientific fields based on the journal in which they appeared. ISI classifies journals by using journal-to-journal citations patterns, expert assessment and other feedback. Hicks and Katz aggregated the subfields (micro-classes) into 11 fields (macro-classes) and three disciplines (life sciences, natural sciences and materials and engineering). Note that arts, humanities and social science were not included in the analysis. The ISI practices of multi-assignment of journals make it possible to create new subclasses of those journals that cross more than one field (interfield) and those that cross more that one discipline (interdisciplinary). Journals that were assigned to subfields that encompassed all three disciplines were called "multidisciplinary".
Hicks and Katz made three additions on an ac hoc basis: 1) journals classified to the ISI subfield "environmental science" were included in the MUL (multidisciplinary) category; 2) journals classified

as "multidisciplinary" by the ISI (e.g. *American Scientist*, *Current Science*, *Nature* and *Science*) were also included in MUL, and 3) five subfields were reassigned to "interfield".

The present study employs the formal method of ISI multi-assignations – we see no theoretical reasons for the argument that some areas are multidisciplinary *per se*. For the same reason, the ISI category "multidisciplinary" is not included among cross-fields. As explained by Katz and Hicks themselves (1997) such journals cannot be considered as publishing interdisciplinary research. In the case that these journals do not have other assignments they will not be included in any of the cross-fields. Instead, journals such as *Science* are considered to be a single-field journal.[6]

Today, many more subfields are included in the ISI database; 219 as compared with 154 in the early 1990s.[7]. We have classified these into the macro-classes proposed by SPRU in the same manner as Hicks and Katz. It should be observed that the ISI assignments are revised each year. Our analysis is based on articles and reviews only. Swedish addresses have been unified in a detailed process where all unique entries have been scrutinised by hand. Our set of data covers the period 1982–2003, while Hicks and Katz covers 1981–1991. This gives us the opportunity to study what has happened ten years after the analysis by Hicks and Katz.

Literature overview

For many observers, the question "Where is science going?" is closely related to the issue of multi- and interdisciplinarity (ARC 1999, NAS 2004). Recently, several articles have been published in journals and an intensive scholarly discussion is now ongoing.[8]

Morillo et al. (2003) describe and discuss many of the problems related to finding a solution to the question of how to measure interdisciplinarity in research. The Spanish group concludes that multi-assignation is an adequate method for giving a broad view. However, there are several problems on a more detailed level. Based on their research, they propose a clustering technique for grouping different areas of interdisciplinarity, depending on the combination of, on the one hand, (number of) multi-assignations per area and, on the other hand, grade of external assignations per area.

The Spanish group has also published a study that tests the multi-assignation method (see Morillo et al. 2001). Their study on chemistry areas reports a convergence between the ISI multi-assignations, percentage of extradisciplinary citations, and the Chemical Abstracts multi-assignation by sections. Closer scrutiny reveals that there is no necessary relation between assignations and interdisciplinarity. However, an area that has a documented widespread relation to other areas did not appear to be multidisciplinary according to the SPRU method, and vice versa. Still, the method is interesting due to good research economy.

Morillo et al. (2003) conclude that the method of using multi-assignations as a proxy for interdisciplinarity is valid in an overall sense. However, they do not consider multi-assignation in categories "as an appropriate indicator, since it is artificially limited by the needs of the classification" (Morillo et al. 2001). Due to this position they did not apply any trend analysis (publications over time) according to the ideas of Hicks and Katz. Even if the Morillo group is perfectly correct in its characterisation, we would be interested to see what would happen if the database were used for these purposes.

Another limitation is that they only touch upon the question of whether other structural dimensions are involved. The statement by van Raan (2000) that "*technology acts as a bridge between the different scientific disciplines, and without technology domains of human knowledge would remain largely isolated*" hints at the problem involved. This observation is an invitation to conduct an analysis of the role of applied engineering and materials science in the process of interdisciplinarity.

Results: increased interdisciplinary research

Morillo et al. (2003) have reported descriptive data on multi-assignations in the ISI database, e.g. half of the journals in each category are multi-assigned. Also, there are small but significant differences

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[6] Cf. Morillo et al (2003), p. 1239.

[7] Please, observe that **social science, arts and humanities are excluded from our investigations.**

[8] Bordons et al. (2004), Braun & Schubert (1999), Laudel (2002), Pierce (1999), Qin et al (1997), Rhoten (2002), Rinia et al (2002a), Sandström et al (2005), Schummer (2004), Small (1999), Weingart (2000).

between macro-classes: the area of clinical medicine has a lower rate of multi-assignations, while other areas seem to be quite similar in this respect.

Figure 2 shows the percentage of cross-field documents in the ISI database during a 22-year period, i.e. 1982–2003. While single-field articles have an annual average growth of 3.07%, articles in cross-field journals have a growth of 8.27% per year (geometrical mean). While the United States levels off, the EU countries (EU 15+Norway) show a steady increase of "interdisciplinary" articles. Sweden follows the EU trend.[9]

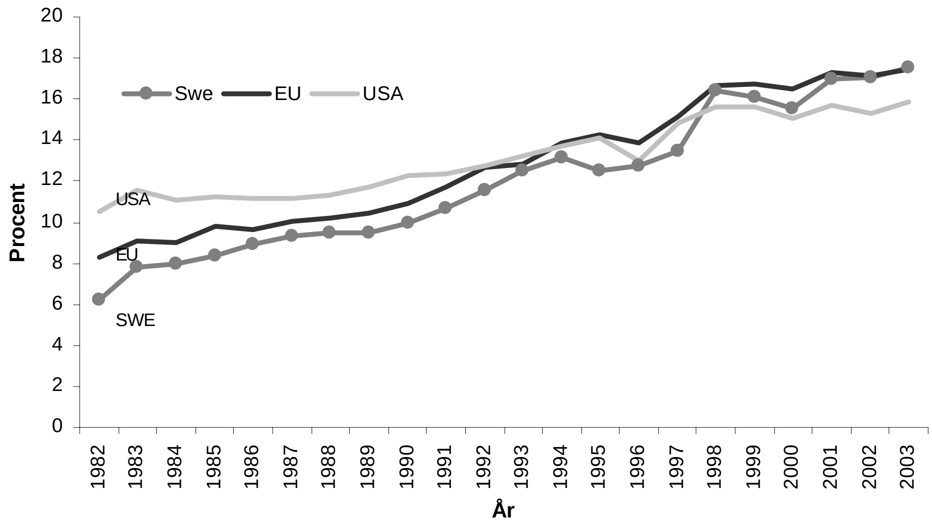

Figure 2. Percent articles in cross-field categories of total articles 1982-2003.
Source: Thomson ISI Web of Science

By looking closer at the assignment of subfields, it appears that perhaps the ISI were lagging in their procedures during the 1980s. During the first half of that decade, about 10% of the journals have blank subfields (approx. 400 journals). Later, until the beginning of the 1990s, they assigned almost all of the journals to one or more subfields. During that decade, the number of journals in the database was continuously growing, and several European journals were added. In 1997, ISI decided to rearrange the subfields to introduce several new categories, e.g. in nearly all fields ISI created a category for interdisciplinary journals (Table 1). From 1991 and onwards, journal issues in the category "multidisciplinary sciences" showed a yearly decrease of nearly 6% (from over 1000 to around 500). To a large extent this explains the marked increase of articles in 1998. Also, this illustrates some of the problems associated with using a database where categorisation is a dynamic process influenced by the studies of science policy. It is most likely that the work of Hicks and Katz (1996) was an impetus for ISI to rearrange and develop new subfields.

Table 1. Examples of subfields introduced into the ISI database from 1998.

ISI subfield
AGRICULTURE, MULTIDISCIPLINARY
CHEMISTRY, MULTIDISCIPLINARY
ENGINEERING, MULTIDISCIPLINARY
GEOSCIENCES, MULTIDISCIPLINARY
INTEGRATIVE & COMPLEMENTARY MEDICINE
MATERIALS SCIENCE, MULTIDISCIPLINARY
MATHEMATICS, INTERDISCIPLINARY APPLICATIONS
PHYSICS, MULTIDISCIPLINARY
PSYCHOLOGY, MULTIDISCIPLINARY

Source: Thomson/ISI Web of Science.

[9] It should be mentioned that the ad hoc method of Hicks and Katz gave a figure of 18% cross-field articles already during the 1980s (see Hicks and Katz 1996, p. 388).

Citations to Multi-assigned Journals

When analysing cross-field articles it is necessary to relate these to single-field articles in various ways. First, before we start an analysis based on citations, we display the distribution over time of different types of articles. It appears that the cross-field articles represent a growing category, but what types of categories are losing their shares? Splitting the single-field category into two groups, reveals that the larger ones (chemistry, medicine and physics) are losing their share, while the smaller ones (agriculture, engineering, earth sciences, ICT, materials science, mathematics etc.) are holding their share (see Figure 3).

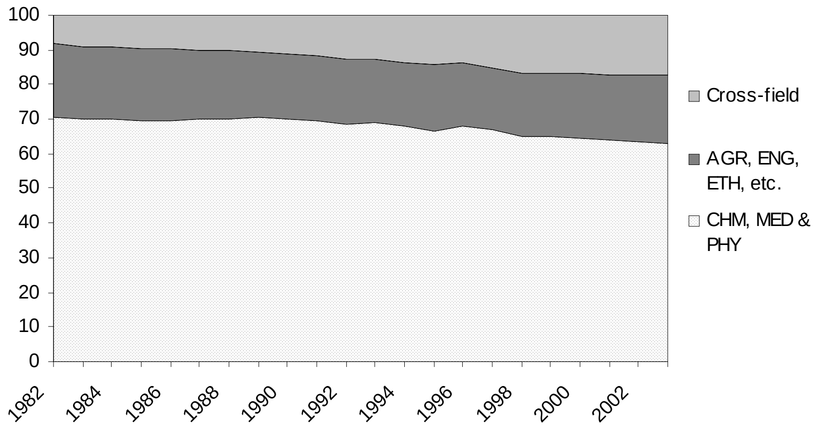

Figure 3. Percentage of articles (EU 15) distributed over categories, cross-field, and two set of single-field 1982-2003.

If we relate this to citations, we get a rough idea of trends in the quality dimension. To do so we use the ratio between citations and articles in the respective SPRU macro-classes. The categories with chemistry, medicine and physics are increasing slightly, which indicates that articles in those categories receive more citations per article. Apart from the last two years, the cross-field categories are quite stable, and the small single-field categories have experienced a negative trend since the mid 1990s.

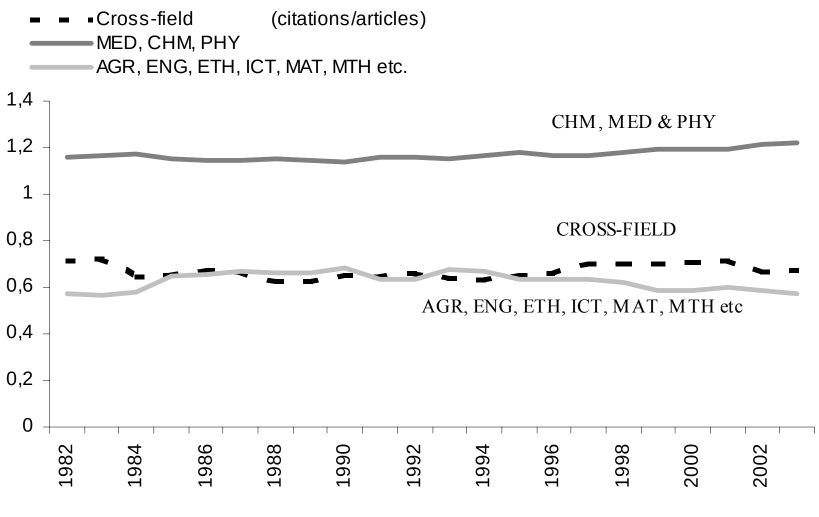

Figure 4. Ratio between citess and articles for three groups of SPRU macro-classes 1982-2003 (EU 15+Norway).

With this background, we move on to an analysis based on countries and focused on comparisons that are relevant for Swedish science. Out of the fifteen European countries we have selected six for a more detailed analysis, three Nordic countries (Denmark, Finland and Sweden) and three West-European countries (The Netherlands, Germany and the UK). Table 2 indicates few differences among the countries in the last period (2000–2003). Obviously, the countries display different historical trends, as shown in the table. Denmark, Finland and Sweden move from a low share in the first period to a high share of cross-field publications in the last period, i.e. 2000–2003. Finland and Sweden are the countries with the highest share of cited articles. Consequently, the ratios for these countries are somewhat higher than are those for the others. The United Kingdom and the United States have much lower ratios. (US, which is not displayed, is well below 0.6 up until 1998). One of the explanations for this might be that the engineering sciences tend to have a lower ratio.

Table 2. Percentage of articles (fractionalised) and citations (fractionalised) in cross-field journals of total articles for six countries.

	1984-87	*1988-91*	*1992-95*	*1996-99*	*2000--03*
A	**Articles**	**Articles**	**Articles**	**Articles**	**Articles**
Denmark	7,35	9,40	12,25	15,88	16,93
Finland	8,01	10,43	12,19	14,10	16,93
Sweden	8,65	9,91	12,41	14,67	16,79
Netherlands	12,15	12,41	14,17	16,23	16,63
Germany	11,01	11,74	13,70	14,76	16,04
United Kingdom	8,81	10,13	12,82	15,06	15,80
B	**Citations**	**Citations**	**Citations**	**Citations**	**Citations**
Denmark	5,70	6,67	8,56	11,17	11,86
Finland	5,95	7,18	8,01	9,69	12,80
Sweden	6,16	6,81	8,27	10,49	12,23
Netherlands	8,28	8,18	9,57	10,98	11,39
Germany	7,42	7,55	8,70	10,07	11,46
United Kingdom	5,23	6,13	7,94	10,30	10,23
	B/A	**B/A**	**B/A**	**B/A**	**B/A**
Denmark	0,78	0,71	0,70	0,70	0,70
Finland	0,74	0,69	0,66	0,69	0,76
Sweden	0,71	0,69	0,67	0,72	0,73
Netherlands	0,68	0,66	0,68	0,68	0,69
Germany	0,67	0,64	0,63	0,68	0,71
United Kingdom	0,59	0,61	0,62	0,68	0,65

Source: Thomson/ISI Web of Science (1984-2003)

Interdisciplinarity at Swedish Universities

As mentioned above, Hicks and Katz established seven categories of cross-field publications. Figure 5 shows the publications rate of Swedish universities in these fields during the period 1988–2003. The interdisciplinary fields of NAENMA (natural, engineering and materials), LINA (life sciences and natural sciences) and IFLI (interfield life sciences) have the largest share of total output and a steady growth. The other cross-fields seem to have a modest increase during this period. This indicates a wide scope of interdisciplinary publications in the country.

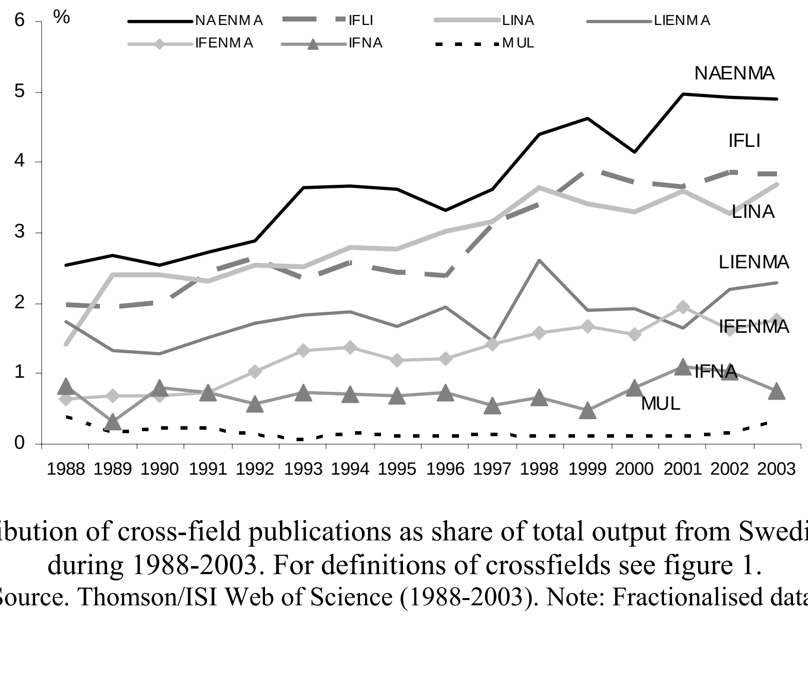

Figure 5. Distribution of cross-field publications as share of total output from Swedish Universities during 1988-2003. For definitions of crossfields see figure 1.

Source. Thomson/ISI Web of Science (1988-2003). Note: Fractionalised data.

Compared to other performing sectors like institutes and companies, university research might have a certain profile – more basic than applied and perhaps more disciplinary that interdisciplinary. In this section of our paper we will use data from Sweden, a country for which we have unified addresses. The objective is to illustrate whether there are differences between the performing sectors. From a Swedish perspective it is surprising that the research institute sector, which has a close relation to industry-driven "collective research", seems to emphasise publications in the cross-field area of LINA (interfield natural science). The share of cross-field publications in that sector is around 25% (2001–2003) and the growth in numbers is almost 9% per year.

Table 3. Distribution among cross-fields per performing sector in Sweden 2001-2003.

	Industry	Res Inst	Universities	Univ Hosp
NAENMA	26	19	30	0
IFENMA	11	12	8	3
LIENMA	10	11	10	22
IFLI	8	18	27	47
LINA	42	23	18	26
IFNA	3	16	7	0
MUL	1	1	1	2
Total	100	100	100	100

Source. Thomson/ISI Web of Science (1988-2003). Note: Fractionalised data.

Looking more closely at the university sector in Sweden we find that universities with schools in engineering (Royal Institute of Technology KTH, Chalmers CTH and Linkoping LIU) have a large share of their publications in NAENMA, LIENMA and IFENMA. This makes sense as these categories seem to be dominated by areas of engineering science and technology. Universities with a higher share of natural science – Stockholm, SLU (Agricultural Science), Uppsala, Lund and Gothenburg are stronger in LINA, and universities with a medical faculty (Uppsala, Lund, Gothenburg, Karolinska and Umea) are strong in IFLI. This is in accordance with the actual faculties at these universities. In this respect the indicator and the categorisation are relatively accurate.

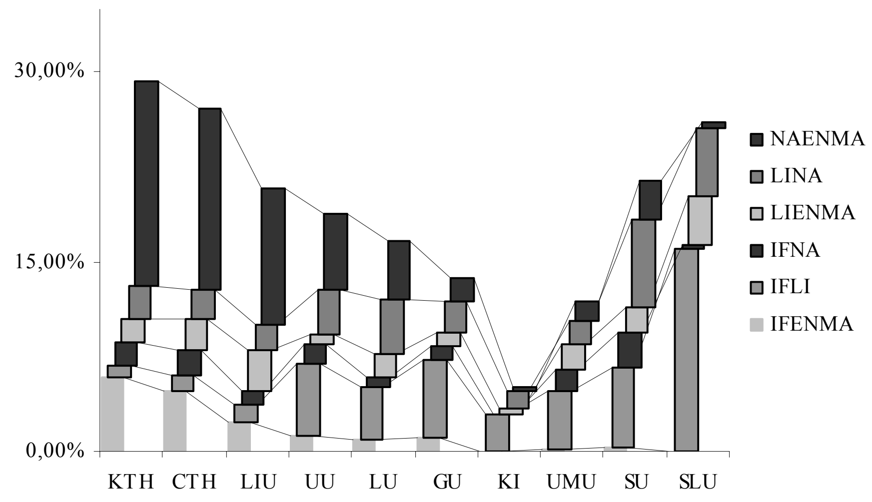

Figure 6. Cross-field publications as share of total publications during the period 2000-2003 at Swedish universities. Note: KTH=Royal Inst of Tech; CTH=Chalmers; LIU=Linkoping univ; UU=Uppsala univ; LU=Lund univ; GU=Gothenburg univ; KI=Karolinska Inst; UMU=Umea univ; SU=Stockholm univ and SLU=Univ Agricultural Science.

Relative Citation Index for Cross-field Areas

We now move back to an analysis of different countries in a European perspective. The issue of interdisciplinarity can also be analysed from a qualitative standpoint. The measure used here will be the actual field normalised impact (two-year windows) relative to the mean for EU (15), see

Appendix. Our calculations follow the method for what is referred to as the "crown indicator" proposed by the Leiden group (van Raan 2005). Added to that is an index of relative specialisation based on figures for Europe (cf. Glänzel 2000:129 f.). Figure 7 summarises the results of this analysis. At the top right in the figure are the engineering areas where Sweden and the Netherlands seem to be strong in impact and specialisation. At the bottom toward the left of the figure we see a stronger concentration on life science and general multidisciplinarity. According to this analysis, Finland and the UK are the strongest players in the publication market for that type of interdisciplinary research. Again, the result of this exercise is somewhat surprising. We would have expected Finland to be stronger in the engineering areas, but their best quality publications are in the natural sciences. Both Sweden and Holland have strong areas of "big interdisciplinarity" (LIENMA and LINA). The UK has strongholds in areas that can be described in terms of "small interdisciplinarity" (IFLI and IFNA).

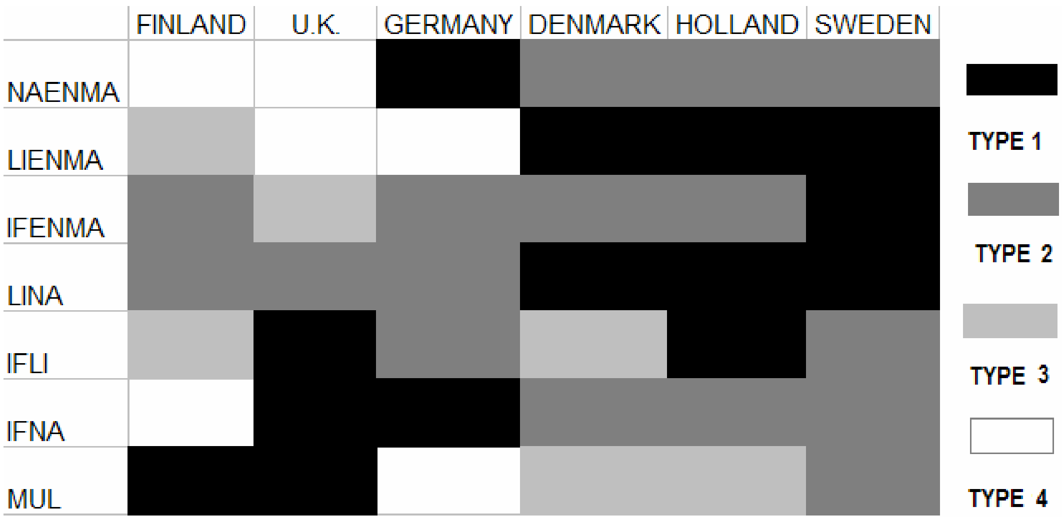

Figure 7. Field normalised relative impact and relative specialisation per country and cross-field during 1996-1999 (2-year window).
Type 1=strong specialisation, high impact; Type 2=weak specialisation, high impact, Type 3= strong specialisation, low impact; Type 4= weak specialisation, low impact

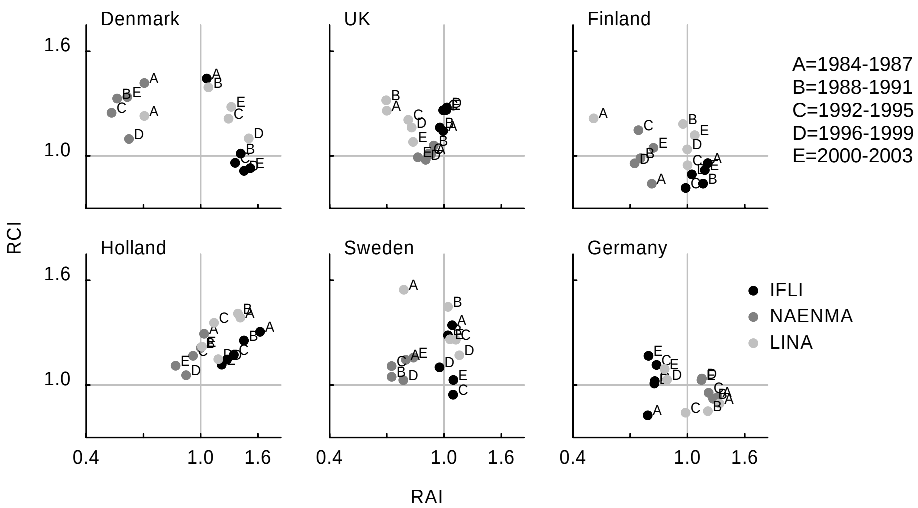

Figure 8. Relative Activity Index and Relative Citation Index for three large cross-fields during five time periods. 1 is the normalised (average) RAI and RCI-position for EU (15) and 1,6 is 60 per cent above average.

A closer look at tendencies reveals that countries have different historical developments in these areas. Figure 8 discloses the time trend over periods for three large cross-fields (NAENMA, IFLI and LINA). Countries such as the Netherlands and Sweden stand out as good performers even if both are coming closer to the EU average. The Danish activity in interfield life science is high, but the rate of citations only average. UK is steadily moving towards the average, but the performance in IFLI is very good. As apparent from Figure 8, Finland and Germany have a lower performance, but are moving in a positive direction.

Conclusion: Applicability or Interdisciplinarity?

In this paper we report several investigations on interdisciplinarity following the Hicks and Katz method. Although the method has been criticised by Morillo et al. (2003) we would argue that there are still many interesting aspects that could be developed further. We have illustrated this simple point. First, the method makes it possible to overview the situation expeditiously. Secondly, the method is largely in line with our intuitive guesses, e.g. when analysing countries or universities or sectors. Thirdly, the method enables one to use time-series analysis, an aspect that certainly could be further developed in our analysis.

As previously mentioned, an interesting dimension of the Morillo (2001) paper can be described in terms of basic and applied research, i.e. the research level dimension. Bibliometric studies indicate that areas strongly related to other fields of research, via citations and references, seem to have a high level of interdisciplinarity. Rinia et al (2002) show that applied areas are largely dependent on results and references from more fundamental areas of research. Hence, applied areas will tend to appear as multi- or interdisciplinary when citation indicators are used.

Contrary to the empirical results of Rinia et al. (2002), the findings of Morillo et al. were negative when multi-assignations were correlated to research level data (Morillo 2003, p. 1240). That part of their study was not described in detail. Therefore, it is not possible for us to evaluate their results. Our impression, using several different aspects of the data, is that there is a connection between applicability and interdisciplinarity underlying the multi-assignations.

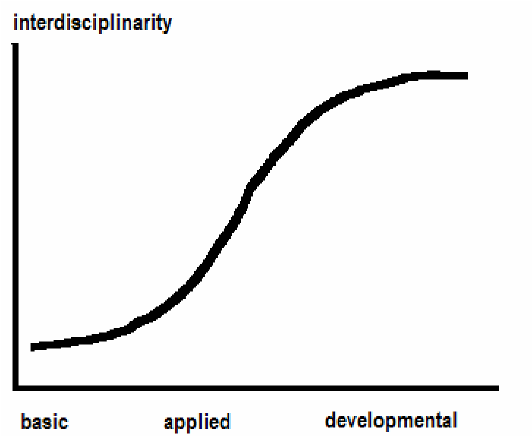

Figure 9. Interdisciplinarity as a function of research level.

A common error involves mixing up type of research with the question of interdisciplinarity between fields of research. Figure 9 presents a theoretical illustration of the problem and underlines the need for discrimination between two different types of policies in relation to single-field and cross-field research. One type of policy would be to move basic research in an upward direction; another type would be to move the research towards development (to the right). The result would be much different, but it is not obvious that it would be possible to follow the former policy by using the Hicks and Katz method as basis for prioritisation.

In conclusion, the Hicks and Katz method using multi-assignations as an indictor of interdisciplinarity is innovative and yields valuable empirical results. Due to good research economy and clear-cut definitions the method is replicable. The main problem is the validity. Further analysis is needed to investigate the relation between applicability and interdisciplinarity.

Appendix A. Calculations of relative activity (RAI) and relative citation (RCI) indices

To calculate publication activity, we counted the number of publications produced in different subject areas in each country. To estimate impact, we also counted the number citations per paper during a 2-year period following publication. The publications and citations per paper were fractionalised with respect to the countries among the contributing authors. Thus, if all authors of a paper come from one country the paper score is 1 while if, e.g. three addresses had country A and one address had country B, A would receive a score of 0.25 and B would receive 0.75. The analysis includes articles and reviews only.

Considering a hierarchical classification of subject categories i.e. from fine graded (ISI subfield categories) to larger disciplines (five major categories), it is possible to construct normalised measures of citation rates and activity. For each country and subfield group a country-subfield index was computed as the paper profile (PP_{AREA}) and citations per paper (CPP_{AREA}).

PP_{SWE} = Sum of paper scores in the subfield / Sum of paper scores for the nearest upper hierarchical level

CPP_{SWE} = Sum of citation scores in the subfield / Sum of paper scores in the subfield

Similar ratios were computed for Europe:

$PP_{EU} = P_{EUROPE\text{-}SUB} / P_{EUROPE\text{-}DIS}$

$CPP_{EU} = CIT_{EUROPE\text{-}SUB} / P_{EUROPE\text{-}SUB}$

The relative activity (RAI) and relative citation (RCI) indices were then computed for each country and subfield as the ratio between CSI and ESA indices:

$RAI = (PP_{SWE} / PP_{EU}) -1$

$RCI = (CPP_{SWE} / CPP_{EU}) -1$

In Figure 8 the logarithm of values is used.

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