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A THEMATIC MOBILITY MEASURE FOR ECONOMETRIC ANALYSIS

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A thematic mobility measure for econometric analysis

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Abstract

Although the concept of interdisciplinary research and interdisciplinary (cognitive) mobility is well established and has become a requisite in research policy, we still know little about the researchers that work at these boundaries or about the consequences for disciplinary fields. The goal of this paper is to identify and describe migration patterns across and within scientific fields. The indicators and tools developed in this context can inform policy-making and help to assess the effectiveness of grant schemes that aim to foster interdisciplinary mobility.

Keywords: Thematic mobility, Interdisciplinary research, Network analysis, Indicators, Engineering

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1 Introduction

Scientific and technological advances have been recognized as one of the main drivers of social and economic development. Policy makers across the world are looking for strategies to encourage scientific production and the exchange of knowledge. Access to top international research and researcher diversity has been identified as an important factor for Europe to compete globally (EC, 2010). In this context, the establishment of research networks and the mobility of researchers is a major policy goal in order to "foster scientific excellence [and to] facilitate knowledge transfer across disciplines, sectors and countries" (ESF, 2013). Researcher mobility has been identified as an important element in forming and embracing social networks and is believed to be vital to further scientific quality, research development and knowledge diffusion. The EU aims to embrace more diverse career paths and to expand the concept of researcher mobility with the aim of fostering and facilitating research excellence and to "counteract brain drain from less scientifically attractive areas" (ESF, 2013).

Since the 1960s there has also been an increased interest in research that crosses disciplinary boundaries amongst policy makers and researchers. Many problems of societal importance are too complex to be fit into traditional academic disciplines requiring the input of researchers with a diverse background. Academics no longer commit themselves to one career but switch effortlessly between sectors and disciplines. The migration of a researcher from one research area to another, i.e. from one research network to another, happens when researchers search for new promising areas that could lead to significant new findings (Gieryn, 1978). Such mobility between fields promotes cross-fertilisation and is of relevance to the birth of new disciplines. New scientific fields and technologies, such as nanotechnology, genomics, synthetic biology, bioinformatics and neurosciences, have emerged in these boundaries. The migration between research areas or networks not only brings about interdisciplinarity; it also enhances productivity and creativity (Sterling, 2007) and results in innovation and exploitable applications (Rosenberg, 1982; Foray and Gibbons, 1996).

Although the concept of interdisciplinary research and interdisciplinary (cognitive) mobility is well established and has become a requisite in research policy, we still know little about the researchers that work at these boundaries or about the consequences for disciplinary fields. While interdisciplinary research has a long history in non-academic settings where research is usually project driven and transition between departments happens effortlessly, academia faces administrative and cultural barriers and sponsoring difficulties that hinder interdisciplinary mobility.

In this context, the goal of this paper is to identify and describe migration patterns across and within scientific fields. The indicators and tools developed in this context can inform policy-making and help to assess the effectiveness of grant schemes that aim to foster interdisciplinary mobility.

2 Background and Hypotheses

2.1 Thematic Mobility

2.1.1 Definition

In this paper we understand 'thematic mobility' as the migration of a researcher or department from one research area to another, or a move from one research network to another (Mulkay, 1974). Thematic mobility in this context has two elements: (1) thematic mobility as a shift "from one area of research to another, either frequently or perhaps at one or two points" (Crane, 1965: 707) and, (2) thematic mobility as a shift back and forth between fields, often in the course of a short time period. The second definition is similar to that of interdisciplinary research (IDR). The concept of thematic mobility does apply not only to individual researchers but can affect whole departments or even a disciplinary field as a whole. In the case of departments, research foci may change: (1) when researchers change their thematic focus or, (2) when new researchers join the department bringing along their established research lines.

The migration of a researcher or departments from one research area to another, i.e. from one research network to another, happens when researchers search for new promising research topics that could lead to significant new findings (Gieryn, 1978). Such mobility allows for knowledge transfer and diffusion between different scientific fields, which could enhance productivity, creativity and innovation. The continuing focus on end-users of research and the push towards research of societal impact further requires research to move outside traditional disciplinary boundaries. The migration between research areas or networks brings about interdisciplinarity, and new scientific fields and technologies have emerged at these boundaries providing evidence of successful cross-fertilisation as a result of thematic mobility.

It can be expected that researchers and departments that are more open to interdisciplinary research also have a higher degree of thematic mobility. By understanding the drivers of interdisciplinary research, which are well documented in the literature, we will also better understand individuals' motivation to move between scientific fields.

2.1.2 IDR and Thematic Mobility

Klein (1990, 2010) points out that not all interdisciplinary research and thus thematic mobility is the same. Much of the research labelled interdisciplinary crosses boundaries where disciplines already overlap or are close. She refers to this as narrow interdisciplinarity. Fields involved in such narrow exchanges are part of the same scientific area (e.g. life sciences). As Huutoniemi et al. (2010) point out, exchanges between related fields are not uncommon and already well-established due to related theories, methods and dissemination norms. On the opposite end of the scale, Klein considers wide or broad interdisciplinarity. Here disciplines from different traditions cross boundaries and integrate knowledge from outside their traditional areas, for example integrating genetics and music. Huutoniemi et al. (2010) stress that broad interdisciplinarity is difficult to achieve as there is little compatibility between fields as new methods or theories have to be accepted.

Shinn and Benguigui (1997) apply a similar scale to thematic mobility. They define narrow mobility as a change of research question within a subfield and wide or broad mobility as a change of discipline. Between these two far ends of the scale they observe mobility between subfields of a discipline or mobility at the interface of two disciplines. Further, they emphasise that researchers can also change the material or instruments they work on.

Rafols and Meyer (2010) use the term cognitive diversity to describe interdisciplinarity. They contest that knowledge integration happens without necessarily breaking down disciplinary boundaries and that the concept of cognitive diversity accommodates interdisciplinarity, and thematic mobility, within and beyond established disciplines.

Amongst the existing scientific disciplinary areas are some that are more open towards interdisciplinary research (Klein, 1990, 2010). Unrestricted disciplines, which include most social sciences, are described as open to outside disciplines (Pantin, 1968). They could be considered less codified and more fragmented, allowing external influence from other research areas. Also applied fields with a vocational element, like engineering or medicine, can be considered more integrative and intrinsically interdisciplinary due to their wider scope and application (Heckhausen, 1972). Restricted disciplines, on the other hand, show fewer ties with other disciplines, a higher level of codification and a more consistent theory (Pantin, 1968). The physical sciences and economics could be considered as closed disciplinary areas.

These patterns are confirmed in empirical analysis based on citation patterns. Rinia et al. (2002) analyse cross-citation patterns in different scientific fields and find that physical sciences have high levels of self-citations and weak ties with other disciplines, while psychology and engineering have low levels of self-citations. Crane and Small (1992) look at social science disciplines and showed that economics has a strong disciplinary structure, while sociology is lacking a universal theory and draws from other fields, including economics. Rinia et al. (2002) also investigate subfields of physics and find that instrument or material based research areas, such as microscopy or crystallography, are more interdisciplinary than theoretical fields like nuclear physics or particle physics. These structures are relatively persistent across time, as Porter and Rafols (2009) have shown. Fields that are less restrictive allow for more mobility, specifically inflowing mobility, while restricted areas hinder mobility and may only promote the outflow of researchers.

2.2 Push and pull factors of thematic mobility

2.2.1 Literature Background

Huutoniemi et al. (2010) argue that IDR is driven by specific research goals that demand new approaches from outside traditional boundaries. IDR approaches could be sought as they are "expected to lead to a more profound scientific understanding or more comprehensive explanations of the phenomena under study" (Huutoniemi et al., 2010: 88). Hence, IDR in this context primarily arises from the desire for knowledge and understanding. Similarly, thematic mobility occurs when researchers search for new promising areas that could lead to significant new findings (Gieryn, 1978).

However, while researchers may choose to enter a new research area due to intrinsic research interests, they often respond to external factors. Researchers change their thematic focus in response to supply or demand shocks (Borjas and Doran, 2012). Even if these external factors do not directly require thematic mobility, they may create an environment that rewards or inhibits its development (ESF, 2013).

A demand shock is an event that influences the demand for a specific product or service. In economics this is considered a sudden event that has a temporary effect, but could result in a long-term change. Demand shocks can be caused by increases or decreases in government spending or tax rates. In our context, lack of recognition can increase the likelihood to change research area as existing research lines are deemed to be unsuccessful (Crane, 1965). Garvey and Tomita (1972) found that 48% of researchers in their survey moved to a new field, primarily due to the end of a project. This change is often accompanied by a change of institution. Crane (1965) further elaborates on reasons for thematic mobility and quotes university or lab requirements that may lead to thematic mobility, as the new institution does not facilitate a prior research line.

Supply shocks, on the other hand, are caused by an increase in the supply of a specific good or service. A positive supply shock would increase the availability of the product resulting in a lower price or value, while a negative supply shock increases the value of the good. In the context of research, new discoveries or technologies provide a supply shock that opens up a new research field. As a result more researchers start working in this area, thus they are thematically mobile. Rappa and Debackere (1993) find that young researchers are most likely to move into new areas as they become available. At the same time, new discoveries may make other pre-existing research lines obsolete resulting in a negative response as these areas dissolve and force researchers to find new areas of research. Borjas and Doran (2012) look at a negative supply shock where the number of researchers contributing to a specific area of research increased greatly. They analyse the effect of the influx of Soviet mathematicians on the thematic mobility of American mathematicians and find evidence for crowding out. As Soviet researchers enter the field, less successful American researchers are forced out and move to other areas of research. Thus, external demand for specific research areas and competition in the field influence a researcher's likelihood to be thematically mobile.

While supply shocks can be important drivers in opening up entirely new areas of research, demand shocks explain the reasons for thematic mobility for the majority of academic researchers.

2.2.2 Hypotheses

Prior literature has seen thematic mobility primarily as a reaction to external research developments. As research areas become more contested, only the most successful researchers are able to continue in their research tracks, while others move to new areas of research when existing research lines are unsuccessful (Crane, 1965). Also, Borjas and Doran (2012) confirm, that the most successful and reputable academics are less likely to leave their area of research. Problems of researchers to publish outside their previous area of research further decrease potential thematic mobility (ESF, 2013). New guidelines have to be learned and new networks have to be established to succeed in the new field. As a consequence, young researchers are over-proportionally seen to abandon their research lines in favour of new topics or diversify, in an attempt to enter new or more successful areas of research

Rappa and Debackere, 1993; Rhoten and Parker, 2004) or due to the end of a project contract (Garvey and Tomita, 1972). As a result we suggest that younger and less productive researchers are more likely to change research area as an attempt to move into more successful research lines. We further suggest that successful researchers are less likely to change research area as they rely on their established networks and expertise.

On the other hand, Yegros et al. (2013) have shown a positive link between IDR and success as measured in citation counts to publications. Thus, while successful researchers may be less likely to change their research lines, researchers at the boundaries between disciplines could be more successful than truly disciplinary researchers. Larivière and Gingras (2011) looking at all articles published in Web of Science in 2000 suggest that an optimum degree of interdisciplinarity could exist, and that there is a threshold in the level of interdisciplinarity beyond which marginal returns in terms of citations decrease. Similarly, more successful researchers may experience more thematic mobility up to a threshold beyond which more success means more disciplinary specialisation. Thus, we could expect a curvilinear relationship between success and thematic mobility

H1: *Young researchers experience a higher degree of thematic mobility.*

H2: *Most successful researchers are least likely to be thematically mobile. Thematic mobility is highest for researchers with mean levels of success.*

The push of young and less successful researchers towards new areas of research is closely related to their interaction with local peers and organisational framing of their work. Most labs have an overall orientation towards continuity and may deter individuals from changing their research line (Shinn and Benguigui, 1997). At the same time researchers that newly enter a department will be required to adopt exiting department research lines. Shinn and Benguigui (1997) analyse thematic mobility at two research centres in France. They find that the structural elements of the organisation are important in determining individual mobility. Researchers at the larger research centre with a federal structure were more mobile as they were better positioned to find new collaborators and form new teams. The internal authority of the centre and their linkages with outside institutions was seen as important predictors for thematic mobility. Further, centres with a niche expertise are less likely to accommodate thematic mobility of their staff (Shinn and Benguigui, 1997). Centres that foster IDR and thematic mobility are also less hierarchical and have lower levels of department differentiation (Hollingsworth, 2008). Hollingsworth and Hollingsworth (2002) also point out that centres that are too large, are less able to provide an environment that fosters the formation of new teams and networking. We could therefore expect an optimal size to exist for thematic mobility.

H3: *Researchers at larger institutions (with many subgroups) have a higher degree of thematic mobility. Researchers at niche departments with niche interests have a lower degree of thematic mobility. Thematic mobility is lower for very large department sizes.*

An additional organisational barrier to thematic mobility is a departments' tendency to reproduce themselves (Hollingsworth and Hollingsworth, 2000) and to be very prescriptive in the research lines they tolerate (Shinn and Benguigui, 1997). This culture is best observed through peer effects. Research problems are guided by those in authority (research group leaders). If researchers can observe thematic mobility amongst their leaders they are also more likely to pursue new research lines themselves.

H4: *There is a positive relationship between the researcher's thematic mobility and the degree of thematic mobility of professors in the department.*

The above discussion indicates that thematic mobility is often prompted by job mobility. Researchers that enter new organisations and projects are required to change research lines (Garvey and Tomita, 1972), as new institutions do not facilitate a prior research line (Crane, 1965). Shinn and Benguigui (1997) also observe that researchers that want to change research lines often feel the need to leave their organisation to join a centre that will accommodate their new interests.

H5: *Researchers that are job mobile have a higher degree of thematic mobility.*

Mobility is also related to networks as job mobile researchers will have been able to forge links with researchers outside their organisation. Similarly, links with industry may be indicative of a larger research network that can foster thematic mobility. Links with industry and a focus on market demands, leads to application oriented research that may also drive researchers towards more interdisciplinary approaches (Huutoniemi et al., 2010).

H6: *Researchers that are collaborating with industry and pursue application oriented research have a higher degree of thematic mobility.*

3 Methodology for Measuring Thematic Mobility

Thematic mobility is aimed to uncover and assess the dynamics of a career in terms of research areas, research fields, specific topics or methods associated with a researcher. According to this perspective, mobility can be conceived as either one or any combination of the following cases:

(1) switches between different research areas/fields/topics or methods during a career;
(2) gradual shift or drift of research interest (in the sense specified above) during a career;
(3) parallel (synchronous) diversity of areas/fields/topics in a research profile).

The rationale behind conceptualising mobility in the thematic dimension is that the general performance of a researcher (productivity, career developments, etc.) might be affected by this factor in various ways. A positive effect can be expected when, for example, the change of subject(s) (either by arriving at a dynamically evolving, emerging, "hot" field, or simply by facing new, motivating challenges) increases productivity or gives impetus to individual careers. Also, the recognition, and, thereby, the collaboration opportunities of a scholar might improve within a different intellectual community. However, depending on the parameters of these changes, effects in the opposite direction are equally conceivable. For example, in a field where a researcher's has no or little previous activity, he/she needs to join a new social network that delays his/her recognisable activity; in addition, there is no guarantee to be successful and accepted in the new context.

The present study uses new bibliometric indicators to measure thematic mobility. Given that thematic mobility is conceived as a pattern of a research profile, we apply the most recent toolbox of science mapping through which it can be thoroughly analysed and visualised both a research profile and its evolution. This toolbox has been introduced under the umbrella of IDR. We look at the evolution of research topics in the field of engineering over the life of a department or a researcher. The study will help to learn from research trajectories of individuals and their departments.

3.1 Representing a research profile

In the context of exploring the indicators of inter- and multidisciplinarity, Porter, Rafols, Meyer and Leydesdorff recently elaborated a formal apparatus for assessing the topical/intellectual diversity of a particular body of scholarly literature. The method is designed to be applicable to publication records. With some variation regarding the details of individual experiments, the following common steps constitute the methodology:

1) Basemap. A global science map is formed against which the publication record can be evaluated. The map consists of a proximity network of SCs for journals included in the ISI–Thompson-Reuters databases (WoS) based on their respective citation patterns. In particular, the proximity of any two SCs is calculated via bibliometric coupling relying on the number of common references (also in terms of SCs). The resulting network can be conceived as the current system of the micro-level fields of science. The global science map used in our exercises is presented in Fig 1.

[Figure 1 about here]

2) Research profile. A publication set *P* of a researcher, institution, country etc. (similarly harvested from the WoS databases) is projected onto the basemap, using the fact that P can be expressed in terms of SCs to which the papers in *P* are assigned (in the WoS databases). The result, called a "science overlay map" is a customised version of the global science map, which offers a structural profile of *P*, thus depicting the number, weight and the relative position/distance of SCs present in *P*. In other words, the resulting map (an example of which is presented in Fig 2) can be conceived as modelling the research profile embodied in the publication record *P*.

[Figure 2 about here]

3.2 Measuring the multidisciplinarity of a research profile

The apparatus discussed above provides an exceptional opportunity to quantify various structural features of a research profile, such as the degree of multi- and interdisciplinarity. Beyond qualifying as a method for visualisation, the overlay map is a complex network of scholarly fields that can be subjected to network analysis. An attractive feature of a research profile expressed as an overlay map is that it captures the following aspects:

(1) the number of fields (SCs) constituting a publication portfolio;

(2) the balance of fields or relative weight of each field (SCs) contributing to a publication portfolio;

(3) most importantly, the degree of disciplinary relatedness (cognitive proximity/distance) of those fields.

The rationale behind this model is that the presence of categories distant in terms of the science map contributes more to the degree of multidisciplinarity than the presence of closely related categories, which is not reflected in the sole distribution of the publication record among SCs. That is, a research profile spread over a broader area of the map is indicative of a more diverse profile, than a portfolio with the same number and the same distribution of categories but closely positioned in the network. In fact, the discussed feature is one of the main advantages of using a science map, i.e. a network of disciplinary descriptors, instead of relying on quantitative distributions of those descriptors.

In order to quantify the degree of multidisciplinarity exhibited by such a research profile, the above-referred authors propose a network-based measure of diversity that is sensitive to factors (1)–(3), that is, the number, balance and disparity of fields involved in the profile. The selected measure is the generalised Stirling index, a diversity measure of the following (simplified) form:

$$GSI = \sum_{ij(i \neq j)} d_{ij} p_i p_j \text{, whereby}$$

- d_{ij} is a distance value between fields *i* and *j* in the network (based on the degree of relatedness),
- p_i and p_j are the relative share of category i and j in the portfolio, respectively.

The value of this index is proportional to the quantities (1)–(3) within the publication portfolio: the more distant the areas of research are within the profile, the higher the number of those fields, and the more even the distribution of publications among them are, the higher the value of the Stirling index would be. In this case, the distance value is derived from the edge weights of the network which is calculated as the inverse of the proximity value for any two categories:

$$d_{ij} =_{def} \frac{1}{S_{ij}} \text{, whereby}$$

- S_{ij} is the proximity of categories *i* and *j* upon which the base map is constructed.

As can be seen, this parameterisation of the generalised index relies directly on the definition of the weighted network. There can be, however, other optional measures, —based on the global science map — which can be used for the distance parameter, such as path-based distance measures (see Soós and Kampis, 2012).

3.3 Interpretation as thematic mobility

The generalised Stirling index applied to an overlay map would easily lend itself to an interpretation that optimally serves as the quantification of thematic mobility. The crucial steps for applying this toolbox to model thematic mobility, are the following:

(1) Given a researcher (or research group, institution etc.), the related publication record in the period under study is retrieved. (In this case, the publication record should originate from the WoS databases.)
(2) An overlay map is created via the procedure described below, that is, the publication record is overlaid on the global map of science.
(3) The Stirling index is calculated for the overlay map as a proxy for thematic mobility.

As can be seen, the measure originally proposed to account for the degree of multidisciplinarity, is now re-interpreted as indicating the degree of thematic mobility. Taken in perspective, the reason for this shift is rather straightforward: thematic mobility can be conceived as the amount of multidisciplinarity accumulated throughout a career be it an individual's professional path or the development of an institution's portfolio. By aggregating the publication output for a predefined period, the degree of thematic mobility characteristic of this period can both be visualised and measured via the overlay map and the Stirling index, respectively, obtained for the respective publication set.

4 Thematic mobility in the Engineering field in the UK

4.1 The data

The data we use to test the measure discussed in the previous section come from a longitudinal database of engineering academics (described in further detail in Banal-Estanol et al., 2013). The database contains detailed information on academics that were employed at the engineering departments of 40 major UK universities between 1985 and 2007.[3] The dataset is the first comprehensive longitudinal data available on academic researches that includes the whole population of academics employed at engineering departments over the observation period. Only permanent staff with teaching and research responsibilities was considered (Lecturers, Senior Lecturers, Professors). The database thus includes details of affiliation and rank for each academic.

[3] The original data was collected based on staff registers in academic calendars and on websites, which were available for 40 UK universities (Banal-Estanol et al., 2013).

The project concentrated on the engineering field, as it has traditionally been associated with applied research and operates between the two spheres of fundamental science and application of technology that transforms knowledge from ideas to operational concepts (Foray and Lissoni, 2010). It can be expected to be more dynamic and more integrative and interdisciplinary than other, more basic science fields (Heckhausen, 1972). Rinia et al. (2002) show that engineering is characterised by a great level of links with other scientific fields. They also show that other engineering related fields, such as computer science, environmental science and biotechnology, are characterised by a high index of links with other disciplines. Material science is less strongly related to other fields perhaps due to the limitations and specifics of the materials they used. Rinia and co-authors' analysis gives a first indication of the level of thematic mobility that can be expected in this study.

In order to measure a change in research topics, we focus on a researcher's academic output and, in particular, in his/her scientific publications. We draw on publications from the ISI Science Citation Index Expanded (SCI) and devise measures based on the 244 SCs assigned by the SCI. Data on publications for each researcher was derived from SCI and cleaned manually to assure correct matching of publications to individual researchers (see Banal-Estanol, et al., 2013). The resulting publication database contains information about ISI SCs for each of the publications, which is essential to apply the model detailed above. The search identified 5751 publishing researchers and 82,538 publications with 105,544 researcher-publication pairs. Although all articles considered in this analysis were published in faculties of engineering, we find 183 different ISI SCs associated with them. Table 1 shows a list of the most common primary (first) SCs. We find that 19 SCs account for two thirds of the publications in our dataset, most prominently electrical and electronic engineering (12.9%) and multidisciplinary materials science (9.3%).

[Table 1 about here]

4.2 Descriptive analysis

Individual thematic mobility

Building on the measure described above and using the data introduced in section 4.1 we look at the extent of thematic mobility at the level of the individual. An individual overlay map was constructed for each researcher covering the timespan under study; that is, a research profile aggregated over the period 1985 to 2007 was generated for each researcher via the overlay technique. The timespan was set at the level of the department, from the earliest publication in the sample (1985) to the most recent one (2007), thus almost covering a window of 30 years. The Stirling index was calculated for each individual upon this set of profiles.

Individual mobility values can be read from the horizontal axis in Figure 3. The vertical axis presents the number of individuals for each combined Sterling value. Larger Stirling values present a higher level of thematic mobility.

[Figure 3 about here]

As can be seen from Figure 3, most individual profiles within this community are moderately diversified or even rather concentrated (most values are under GSI = 0.25, which can be considered relatively low, as the next section might reveal via coupling visualised overlay maps with the corresponding GSI-results). Some researchers, however, exhibit relatively high mobility over subject areas; at the other extreme, a very few individual bears no mobility at all (absolute specialists).

Figure 4 shows the distribution of the Stirling index by academic rank. The horizontal axis shows the four academic ranks: lecturer, senior lecturer, reader and professor. Thematic mobility is very similar between the four different ranks and no large difference can be inferred from this graph. All ranks concentrate around a Stirling index of 0.2-0.25.

[Figure 4 about here]

University affiliation and thematic mobility

Information was available for engineering academics at forty UK universities. Figure 5 shows the subject distribution (as measured through the Stirling index) by university. The horizontal axis displays the university codes; the bars indicate the size of the respective department in terms of number of publications. The distribution inside each university indicates that some universities have a higher level of mobility than others. The highest level, with almost 0.3, is the University of Exeter (EX), a relatively small university with a highly diverse engineering department given its links to mining and renewable energies. The lowest levels can be observed in small institutions such as the Universities of York (YO) and Essex (ES) with limited engineering capacity. Amongst the large institutions, Loughborough (LO) and Southampton (SO) presents the highest levels of thematic mobility, having, both of them a strong history in diverse engineering fields. Cambridge (CA) and Oxford (OX) along with Sheffield (SH), are amongst the large institutions with the lowest levels of thematic mobility; this is perhaps due to a more stringent division amongst departments and sub-departments.

These findings suggest that thematic mobility of academics should not be viewed without taking into account the structure of the employing department.

[Figure 5 about here]

Co-authorship and thematic mobility

Previous literature has suggested that interdisciplinarity is primarily owed to co-authorship. Academics may appear to venture into a new area of research when actually they are only contributing with some specialised knowledge to a work outside their core research area. Therefore, it can happen that while the resulting publication may be assigned to a subject category outside their core research area, the researcher remains firmly rooted in his/her disciplinary field.

To address this question, Figure 6 displays the level of thematic mobility by the researcher's average number of co-authors. Researchers with no or with only few co-authors display lower levels of thematic mobility; yet, the difference for researchers with more than two co-authors per publication on average is not significant. We can conclude that while the number of co-authors correlates with thematic mobility, co-authorship numbers do not condition the overall result of thematic mobility.

[Figure 6 about here]

Individual mobility examples

In the second setting, we look at randomly selected individual cases of thematic mobility. Here, we address the profile of individuals under study and that are drawn from three intervals of mobility values (0.1–0.2; 0.2–0.3; 0.3–). The dynamic overlay maps of the individuals are outlined in Figure 7, 8 and 9, respectively. The legend associated with the figures helps to track the changes in terms of disciplines, that is, empirical clusters of SCs indicated by different colouring on the map. The size of the nodes represents the share of a researcher's publications in the respective field.

It can be easily observed that individual 1 primarily occupies two highly related SCs that heavily overlap on the dynamic overlap map. The researcher specialises in engineering and material science with more than 80% of his/her publications in either of these two fields.

Researcher two, with a mobility score of 0.2-0.3, can be seen as the median researcher in our sample. Publications are becoming much more scattered on the scientific landscape; the overlay also becomes more balanced with more equally weighted fields constituting the profile.

Researcher three, with an above average mobility score, has the primary share of his/her publications in fields related to computer sciences. This researcher is therefore primarily mobile inside the discipline. However, the researcher often ventures outside the core field into little related disciplinary areas publishing 38.5% of articles outside the core area of computer sciences.

[Figure 7, 8, 9 about here]

Department mobility example

In order to further demonstrate our results, we selected a UK department that employs 20–30 publishing researchers each given year of the period under study. To track the development of the research profile, we took a series of one-year snapshots of the department's portfolio. For each year, both overlay maps and the corresponding Stirling index were obtained. This exercise produced a (1) dynamic network, that is, a series of overlay maps jointly visualising the year-wise changes or "mobility events" within the profile, and (2) a time series of mobility values recording the extent of the change along the timescale. In other words, this measurement setting is sensitive not only to the scope of the composition of the research but also to the dynamics.

We visualise the development of the scientific fields in the department in Figure 10. The initial composition of the profile (year 1985) and its structure given by, approximately, each passing decade, is being visualised. It can be easily observed that the production of the department has substantially been diversified since the initial year as its output spread out from a concentrated set of SCs and, towards 2007, it populated almost half of the thematic area on the "west side" of the global map. Beyond getting much more scattered on the scientific landscape, the overlay also becomes more balanced with more equally weighted fields constituting the profile.

[Figure 10 about here]

The legend associated with the figures helps to track the changes in terms of disciplines, that is, empirical clusters of SCs indicated by different colouring on the map. While starting from the disciplinary structure, including engineering, environmental science and technology, geosciences and materials science (1985), towards 2007 a whole range of life sciences enters the scene, such as clinical medicine, biomedical science, ecological science, cognitive sciences and agricultural sciences.

This tendency reported by the dynamic overlay map is well detectable through the utilisation of the Stirling index. Measured on each time slice, that is, based on annual overlay maps, changes concerning the degree of multidisciplinarity are quantified and set out in Figure 11 One can observe a clear, almost linear ascending trend between 1985 and 2007, with a peak in this latter year (some fluctuations are also evident from the graph). It should be stressed that, with the very same tool as above, a quite different interpretation of thematic mobility has been gained through this utilisation: instead of an “aggregation function” summarising the degree of multidisciplinarity achieved throughout a period, the evolution of a profile, that is, the dynamics “lagged” within the process is made accessible.

[Figure 11 about here]

5 Econometric application: Drivers of thematic mobility

The above sections described the underlying thematic mobility structure of the engineering population in the UK. This section illustrates the relevance of the thematic mobility measure for econometric analysis by looking at the specific determinants of a researcher’s propensity to change research topic. In doing so, we attempt to answer the hypotheses posed in Section 2.

5.1 Methodology

Our dependent variable is the thematic mobility index (generalised Sterling index) described in section 3 that has been calculated for each researcher and year. The GSI_{it} appears as a fraction that takes values between 0 and 1. In statistical estimations one would also want the predicted values to fall within the same interval. Linear regressions are not suitable for such bounded data as they assume values to occur outside these boundaries. Papke and Wooldridge (1996) suggest a fractional logit regression for handling fractional data. The logistic function is written as: $E(GSI_{it}|x_{it}) = \exp(x_{it}\beta_{it})/[1+\exp(x_{it}\beta_{it})]$, where GSI_{it} is the dependent variable and x_{it} is a set of explanatory factors. The expected GSI_{it} is a function that ensures that the predicted values of GSI_{it} are between [0,1]. The method can be estimated using a generalized linear model (GLM) with a logit link function and a binomial distribution. We estimate clustered standard errors that are robust to heteroskedasticity and correlation between *GSIs* of a given individual.

5.2 Explanatory variables

The dataset of UK engineering academics contains several career characteristics that will be used in the econometric analysis. We hypothesised above, that junior academics are more likely to change thematic area. We measure seniority as the academic rank of a researcher (lecturer, senior lecturer, reader, professor). Additionally we consider the researcher’s age in some specifications. This measure is based on PhD year and career start information. PhD information was taken from *Index to Theses*, an online database which lists theses accepted for higher degrees by the universities of the UK and Ireland. It provides information on PhD institution, year and subject area. If PhD year was after the academic joined a department as a permanent staff or if it could not be collected, the first year of the career as lecturer would be used as a basis for calculation age. Age thus represents the number of years since PhD or since the start of one's career, whichever is earlier. It is only available for a 5058 researchers.

We further suggested that less successful researchers are more likely to change subject areas in search of profitable research lines. We measure success as the average number of citations received until 2008 by the researcher's publications published up to *t-1*.[4] We hypothesised that the effect would be curvilinear and therefore also include the quadratic term.

To measure organisational structure we look at the size of an engineering department in terms of number of academic staff and department productivity. We also add the share of staff and publications by professors in the department to measure fragmentation in the department. These measures exclude the focal academic. We further introduce a dummy that states whether the department is a niche engineering department, e.g. sound engineering or corrosion engineering.

In section two we emphasise the importance of researcher's peers. We measure the potential imprinting effect coming from senior peers (leadership effect) as the average thematic mobility score of professors in the same department. It is of further interest to relate thematic mobility to other types of mobility. Job mobility is measured as a dummy that takes the value one if the researcher was job mobile (has changed jobs) in previous years. Job mobility was measured through affiliation data. If researchers change between the 40 universities, this is recorded in our data and they are considered mobile. Additionally, if researchers join the data as seniors, from a university and department other than the ones coded in our sample, these are also recorded as mobile. The mobility variable turns one the year of the mobility event.[5]

Research networks may further be expressed through contact with industry. We have two measures for researcher's engagement with industry. First, we record if the focal researcher was collaborating with industry through public research grants. We use grants from the Engineering and Physical Science Research Council (EPSRC) that can involve partners from industry. 45% of researchers have contact with industry at some point in their career and 31% of observations show industry involvement in the previous three years. As this measure of

[4] Citation counts are inherently truncated and we miss out future citations. However, Glaenzel et al., (2003) and Adams (2005) find that the bulk of citations usually occur in a three to five-year window. Thus, for the majority of observations we should capture the peak in citations for each publication.

[5] It is one of the biggest caveats of our sample that it does not follow researchers across department boundaries, especially as our concern is thematic mobility. However, to illustrate the use of our indicator and to study the thematic mobility of whole department our data is very useful.

industry involvement may primarily capture the effect of funding, we also include a dummy for funding received in the previous three years. Our second measure of industry involvement is a dummy that states whether the researcher is an inventor. Academic inventors may be closer aligned to application of research, external markets and commercial needs and may therefore be more likely to also shift the thematic focus of their research. Patent data was obtained from the European Patent Office (EPO) database. Database construction required a manual search in the inventor database and matching was done comparing addresses, titles and technology classes for all patents potentially attributable to each researcher. We did not only consider patents filed by the universities themselves, but also those assigned to third parties, e.g. industry or government agencies.[6] We recorded the filing date of the patent as this represents the closest date to invention.

Finally, we emphasised the permeability of different scientific fields, which may affect thematic mobility. Engineering is very permeable and we would expect thematic mobility to be higher. Less permeable fields, such as computer or material sciences, are expected to allow for less thematic mobility. We therefore introduce a series of field controls for the various subfields of engineering based on researcher's PhD topic and current department affiliation for those researchers where PhD information was not available.

We further control for the number of publications over the last three years and the mean number of co-authors during the last three years, which may have affected the thematic mobility measure. We include quadratic terms of both measures as we expect them to be nonlinearly related to thematic mobility. We also include university and year fixed effects to all estimations.

Table 2 summarises the different variables used in the regression and their expected effects on thematic mobility.

[Table 2 about here]

5.3 Results

Results of our GLM model are displayed in Table 3. We take logs of all count variables to account for the skewed nature of these measures. The number of academic staff is reduced to 3408 due to missing values in some of the variables. We always observe thematic mobility in the last year a researcher is present in the sample.

[6] Lawson (2013) showed that amongst UK engineering academics more than 50% of inventions are not owned by the university but by private firms, government or individuals.

[Table 3 about here]

Against our expectation we do not find a negative effect of age on thematic mobility. Younger researchers do not show a higher mobility index than older researchers. At the same time, thematic mobility increases with academic rank, thus seniority. This indicates that professors have higher thematic mobility than junior researchers. Success, as measured through the mean number of citations to prior publications has a curvilinear effect on thematic mobility. We display the marginal effects of success on thematic mobility in Figure 12. Thematic mobility increases for lower citation accounts, but decreases for top performers. This confirms our expectations in Hypotheses 2.

Organisational structure of the department is also correlated with thematic mobility. Size in terms of member of staff has a negative but insignificant effect; however, if measured in terms of publication outcomes it has a positive effect on thematic mobility. The quadratic term is negative but the marginal effects remain positive. Thus, size of the department has a positive effect on thematic mobility only if it is expressed in a higher number of publications. Large departments that do not produce more publications, do not support thematic mobility. Yet, the share of professors in the department, an indication of a highly federalised and fragmented department that may support the formation of new teams, does not affect thematic mobility, and neither does the share of publications by professors in the department.

We further hypothesised that researchers in specialised niche departments are less thematically mobile. Instead, our results show that researchers in departments like sound or naval engineering have a higher degree of thematic mobility than their peers. This may be due to the intrinsic interdisciplinary nature of these departments.

We, however, find no positive leadership effect. Researchers in departments where professors have a high degree of thematic mobility do not show a higher degree of thematic mobility themselves. This may be due to the non-dynamic nature of our data.

Opposite to our expectation we also do not find that job mobile researchers are also more multidisciplinary. Instead we observe a negative despite insignificant effect of job mobility on thematic mobility. As we only observe senior researchers moving within the field of engineering this estimate may not be reliable. Truly thematically mobile researchers might leave the field of engineering and thus our dataset.

Contact to industry has a negative significant effect on thematic mobility. Researchers with more diverse contacts thus do not show an interest in more diverse subject areas. Public funding, however, has a positive effect on thematic mobility as it may enable the pursuit of larger projects. Being and inventor, on the other hand, has no significant effect.

In line with previous literature we also find that researchers in engineering are more multidisciplinary than researchers in computer and material sciences.

Our publication and co-author controls are significant and have a concave increasing relationship with thematic mobility, as expected.

6 Discussion and Conclusions

Although the concept of interdisciplinary research and interdisciplinary (cognitive) mobility is well established and has become a requisite in research policy, we still know little about the researchers that work at these boundaries or about the consequences for disciplinary fields. While interdisciplinary research has a long history in non-academic settings where research is usually project driven and transition between departments happens effortlessly, academia faces administrative and cultural barriers and sponsoring difficulties that hinder such mobility. While researchers may choose to enter a new research area due to intrinsic research interests, they often respond to external factors and change their thematic focus in response to supply or demand shocks. Even if these external factors do not directly require thematic mobility, they may create an environment that rewards or inhibits its development.

In this paper we stated the importance of thematic mobility in relation to scientific advancement. We used a new unique indicator for measuring thematic mobility. First, we introduced a large scale UK dataset and introduced the model for quantifying thematic mobility with a new set of corresponding indicators/measures. Second we presented an experiment on the large-scale UK dataset.

We showed that our measure for thematic mobility based on overlay map techniques with the derived indicators of thematic mobility provides rich structural information on research profiles. For individuals, the tool can convey important structural features of a career. Consequently, this indicator set goes far beyond the capacity of classical evaluative scientometric indicators, while still encapsulating complex information in single-number values. It has also been demonstrated that thematic mobility measures are extremely flexible against the selected unit of analysis. Overlays and variants of the generalised Stirling index can be imposed on any set of (WoS-indexed) publications, representing either an individual’s career, the activity of a research group, an organisation or the field as a whole.

Potential drawbacks of the indicator are placed in the WoS subject categories themselves as well as the requirement to provide individual level publication profiles. WoS Subject Categories. SC-s, however, are journal categories, each containing a set of journals, many of which arguably shows some——or, sometimes, considerable—thematic variability itself. Therefore, thematic mobility in this case would better be called field mobility, as SCs are commonly considered to represent micro-level fields of science. A model with increased sensitivity to thematic trajectories might rely on keywords, references or other paper-level descriptors. Despite all the cons of our particular choice of thematic indicators, a reasonable argument in favour of using SC-maps would certainly be that SC-based measurements provide some robustness for the results. Keywords and other fine-grained thematic descriptors usually produce maps with a huge amount of noise and implied subjectivity for interpretation (a burden on clustering and labelling) which makes the results unstable and hardly reproducible.

A further limitation of the methodology is still grounded in the requirement that any publication record should be identifiable in Web of Science databases in order to qualify as the basis of such analysis. The reason for this requirement is straightforward: since science overlay maps are constructed from WoS SCs, an input set of papers is needed to be assigned to those very SCs before subjected to analysis. (There might be, and indeed exist, other global maps of science as well, relying on other descriptors or databases. However, the Rafols–Leydesdorff map and its derivatives are the most natural choice for implementation mainly due to availability and usability.)

The measure for thematic mobility was also used in an econometric model. We predicted thematic mobility as a function various characteristics at the level of individual and organisation based on a series of hypotheses. Thematic mobility proved to be primarily driven by individual characteristics and less by peer effects. We specifically found that it correlates positively with research quality and with public funding. The paper thus not only provides evidence of the successful application of the thematic mobility measure but also demonstrates its importance for understanding scientific advancement.

7 Future directions

During the development of the measure of thematic mobility, several issues have emerged as paving the path for further improvement and elaboration of this toolbox.

As a promising case of demonstrative applications, an experiment of linking individual mobility with the development of institutional profiles is under way. It is of particular interest how, as in the present case, a staff made mostly of specialists and of a few generalist can build up a community (department) with an increasing overall diversification. Two extremes of the various plausible explanations may be that (1) specialist researchers are being recruited from various fields associated with the department over time or (2) the activity of some generalists dominated the profile. An appropriate, e.g. annual coupling of individual and institutional profiles may provide a quick but telling insight into such structural phenomena of scientific communities.

In order to assist interpretation and comparability, refined versions of mobility indices (GSI-measures) should be developed via normalization procedures. Raw GSI values are hard to interpret without their respective context (such as their relative position in a time series, or the corresponding overlay map).

Most importantly, a prevalent facet of thematic mobility can be said absent from the approach developed above. Although efforts has been taken to grasp the dynamics of research profiles, or individual trajectories over the scientific landscape, plus the measurement is able to capture annual differences in the degree of (annual) interdisciplinarity, it still does not reflect the evolution of the set of fields that constitute a profile. In other words, change in the profile is being tracked by assuming independent cross-sectional patterns, while a natural requirement would be to track the extent of category shifts between cross-sections. The development of such an improvement for our approach is under way.

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Figures

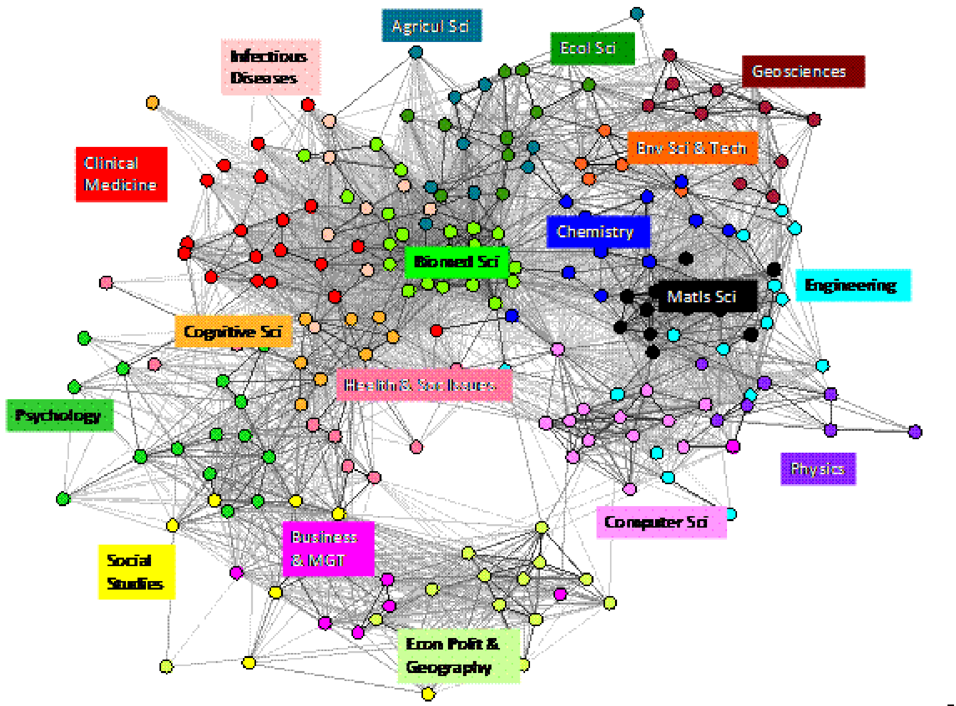


Figure 1 Global science base map (Rafols-Leydesdorff)

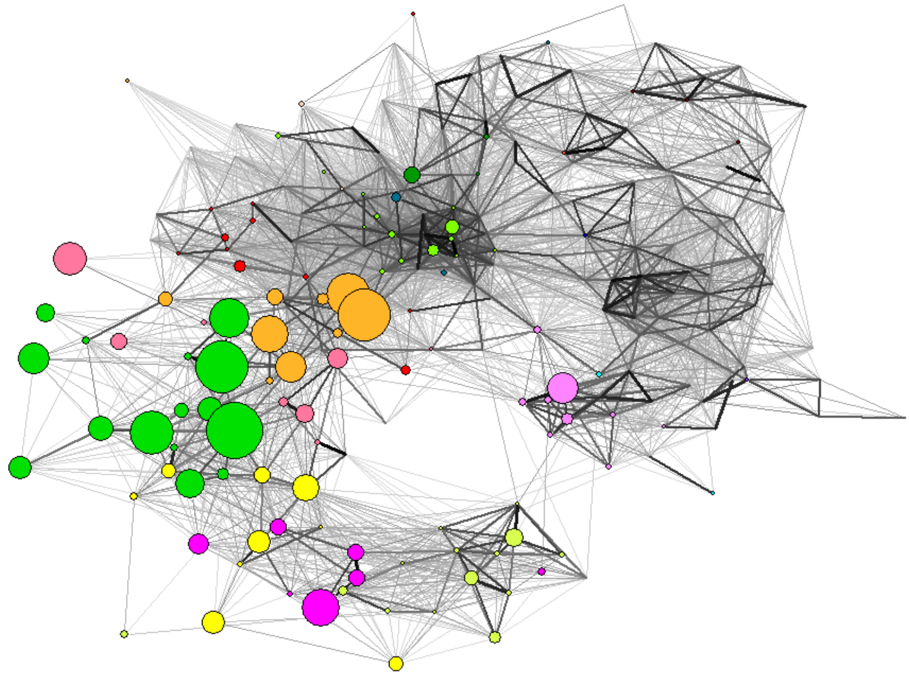


Figure 2 Topic overlay map (Rafols-Leydesdorff)

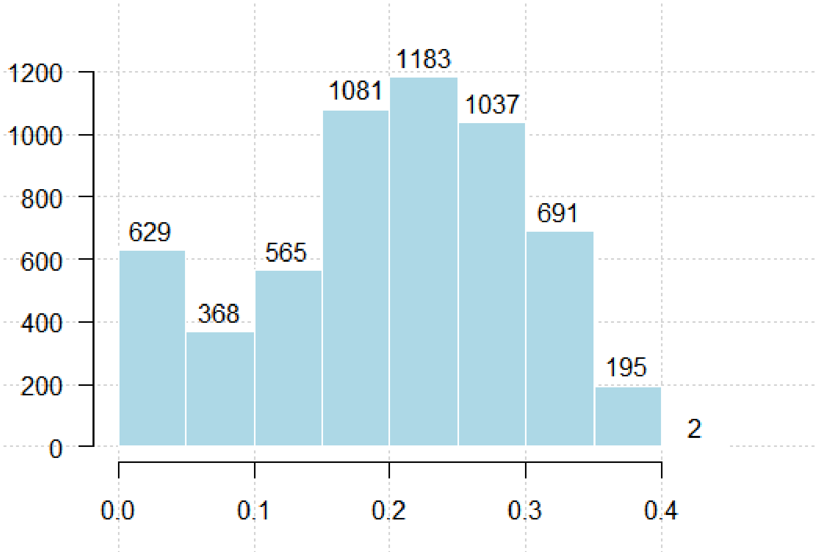


Figure 3 Distribution of thematic mobility within the sample

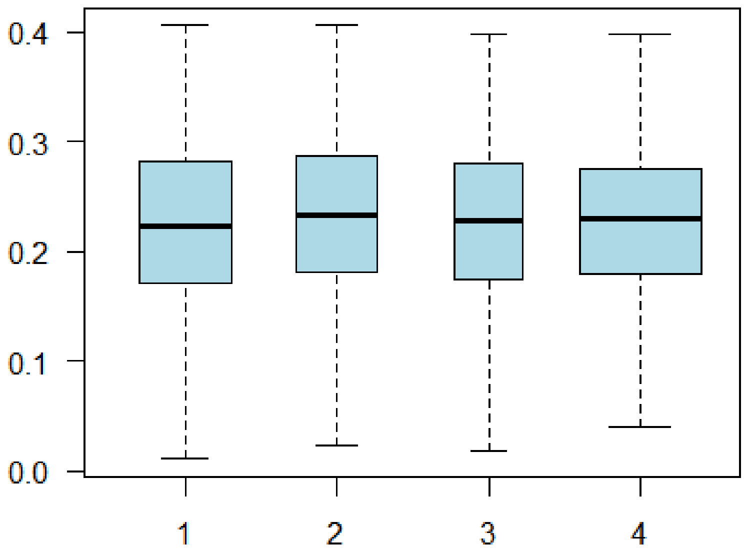


Figure 0 Distribution of thematic mobility by tenure classes (coded by 1, 2, 3, 4)

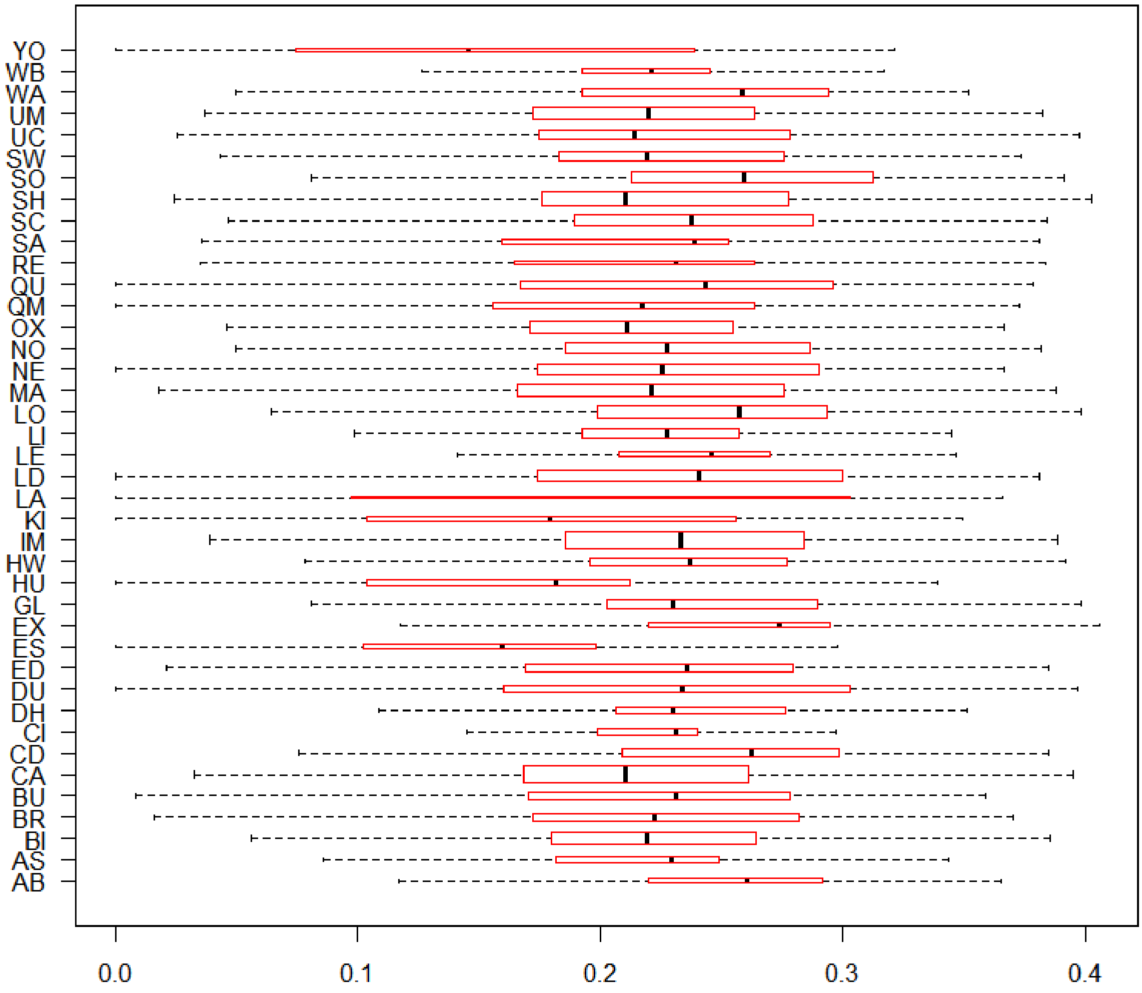


Figure 5 Distribution of thematic mobility by university affiliations

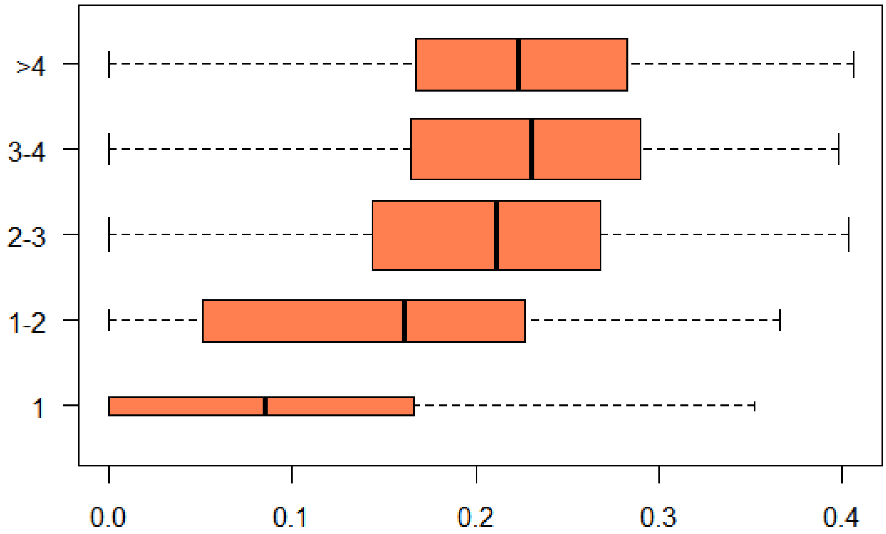


Figure 6 Distribution of thematic mobility by average number of co-authors

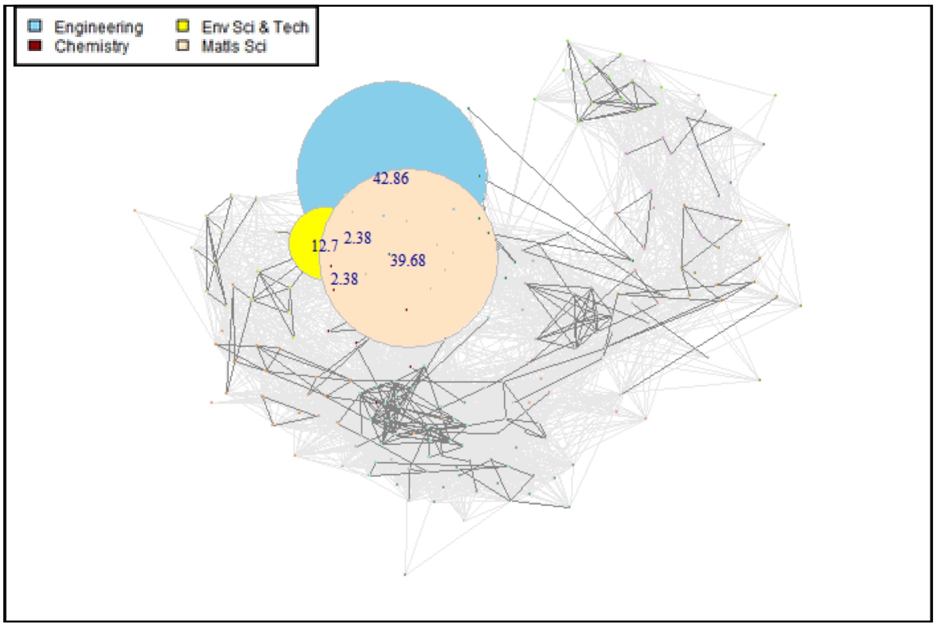


Figure 7 Profile map of randomly selected individual from interval of mobility values 0.1–0.2

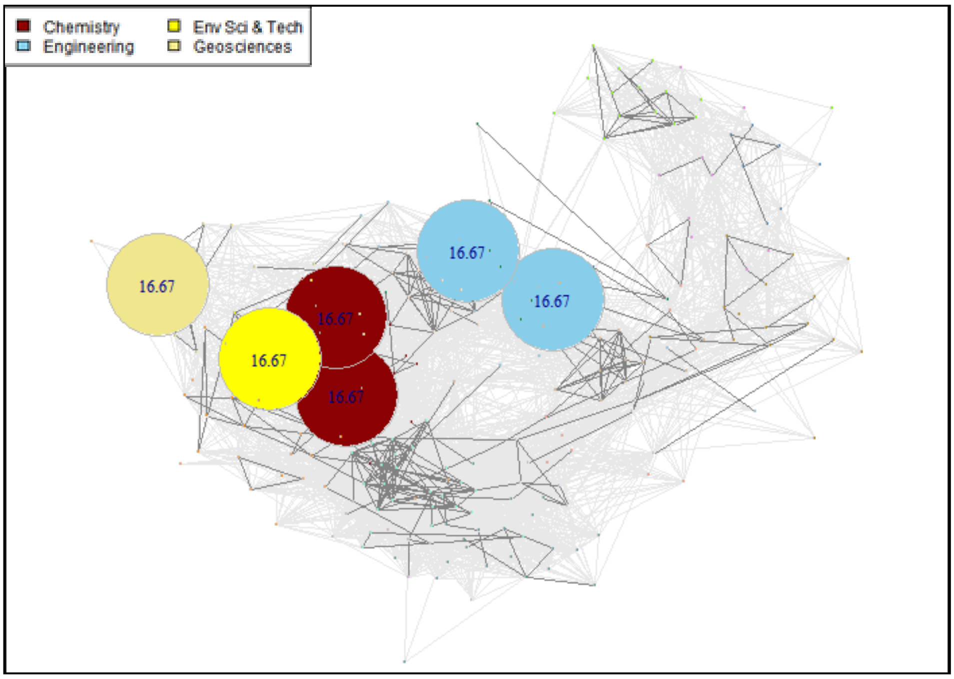


Figure 8 Profile map of randomly selected individual from interval of mobility values 0.2–0.3

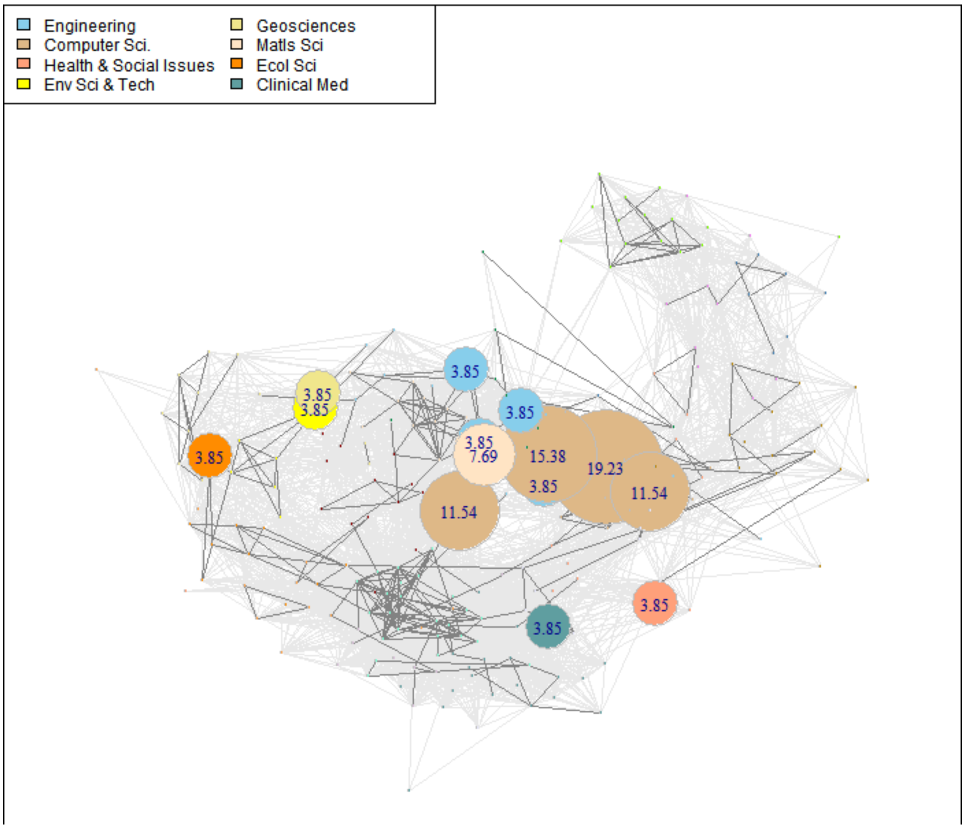
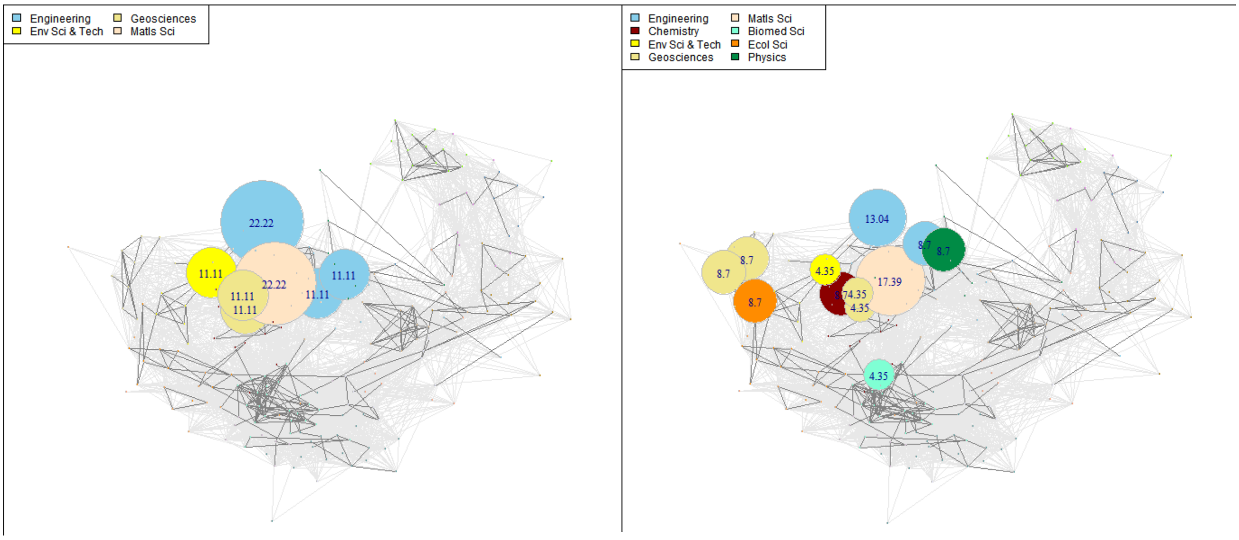


Figure 9 Profile map of randomly selected individual from interval of mobility values 0.3–

1985 **1990**



2000 **2007**

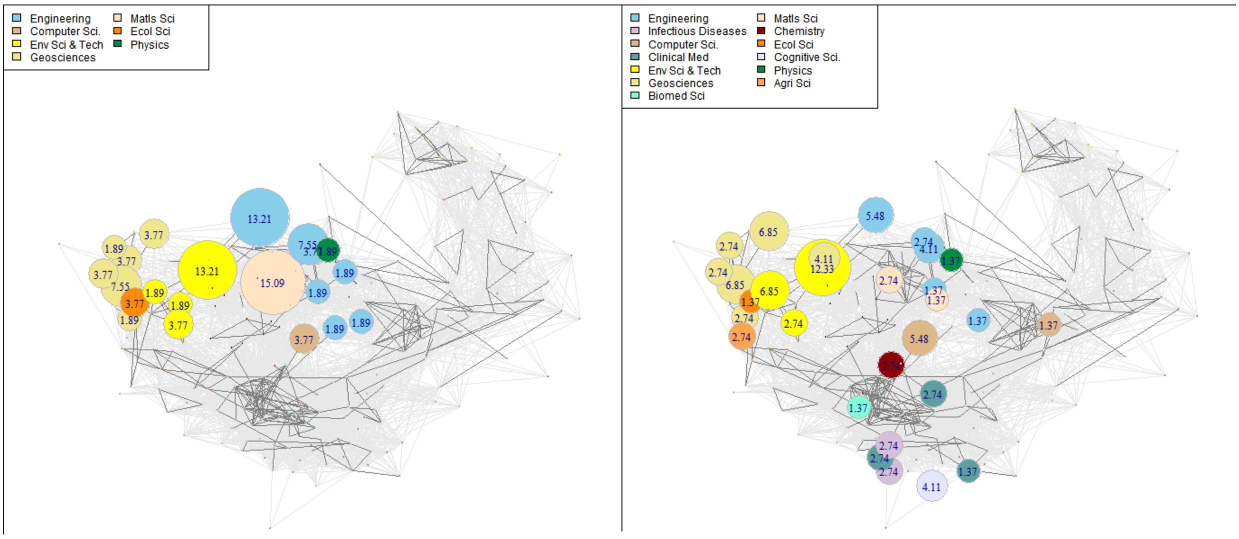


Figure 10 Overlay maps of subject categories at a university

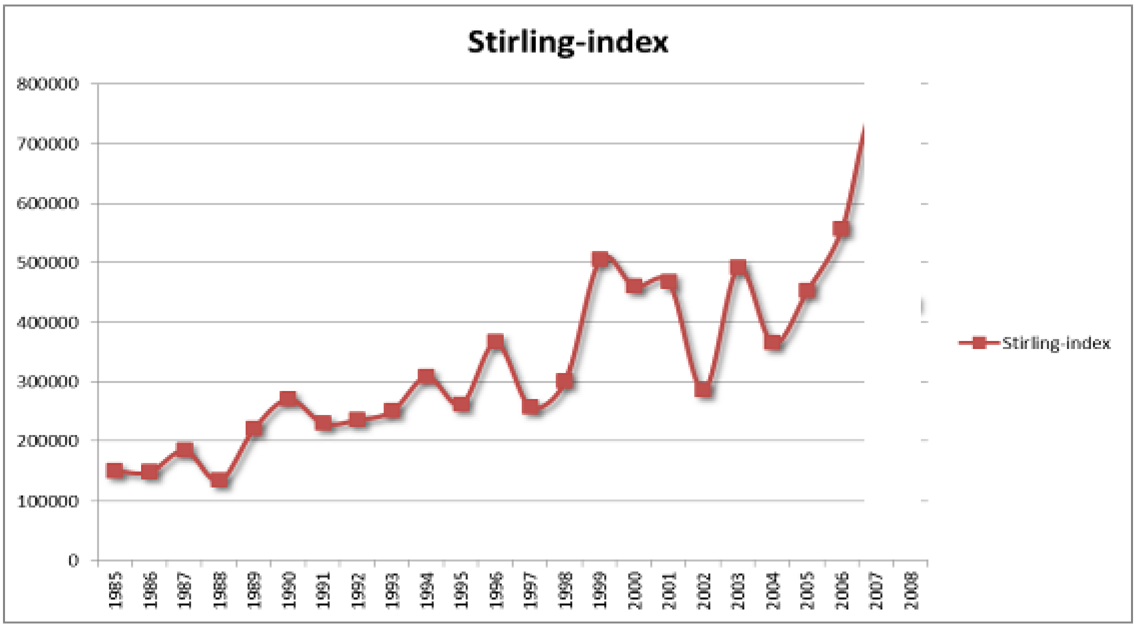


Figure 11 Stirling index of a university

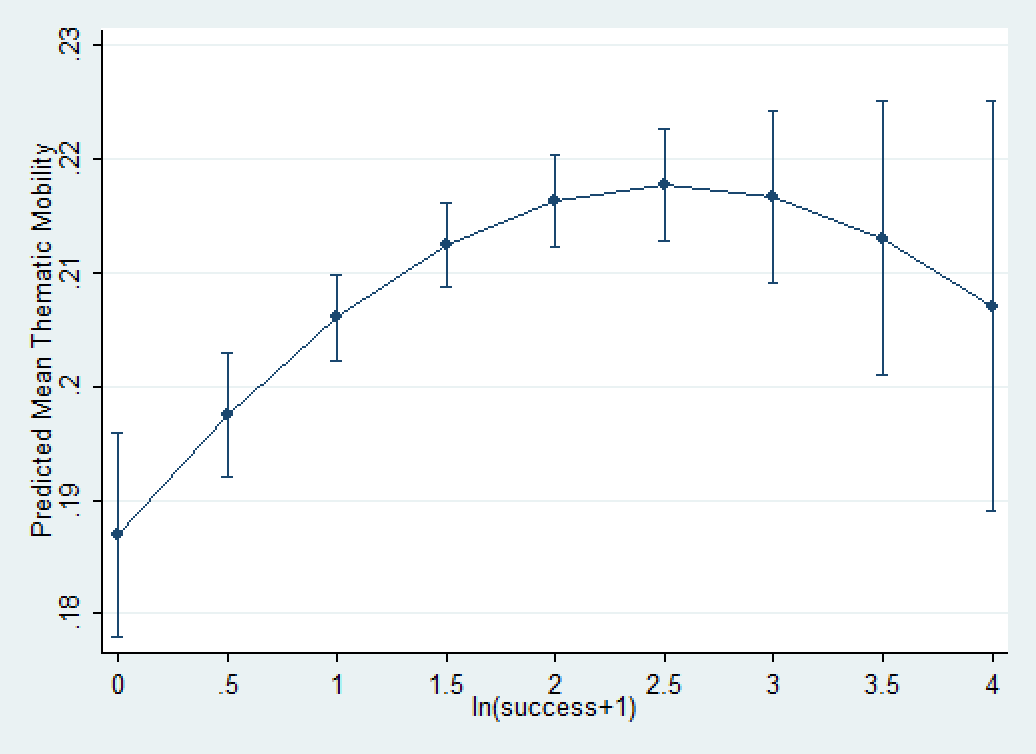


Figure 12 Predicted thematic mobility over mean number of citations

Tables

Table 1 Shares of major subject categories

Subject Category	# articles 1985-2007	Percent	Cumulated percent
Engineering, Electrical & Electronic	10625	12.87%	12.87%
Materials Science, Multidisciplinary	7644	9.26%	22.13%
Engineering, Mechanical	4638	5.62%	27.75%
Engineering, Chemical	3621	4.39%	32.14%
Physics, Applied	2854	3.46%	35.60%
Automation & Control Systems	2730	3.31%	38.91%
Chemistry, Physical	2633	3.19%	42.10%
Engineering, Multidisciplinary	2178	2.64%	44.73%
Engineering, Civil	1936	2.35%	47.08%
Computer Science, Interdisciplinary	1891	2.29%	49.37%
Acoustics	1882	2.28%	51.65%
Optics	1653	2.00%	53.65%
Materials Science, Ceramics	1649	2.00%	55.65%
Physics, Multidisciplinary	1630	1.97%	57.63%
Construction & Building Technology	1608	1.95%	59.57%
Mechanics	1599	1.94%	61.51%
Thermodynamics	1538	1.86%	63.38%
Energy & Fuels	1235	1.50%	64.87%
Polymer Science	1210	1.47%	66.34%

Table 2 Summary of variables used in regression

Variable	Mean	Sd	Min	Max	Expected Effect
Thematic mobility	0.21	0.09	0	0.40	
Lecturer	0.28	0.45	0	1.00	
Senior Lecturer	0.28	0.45	0	1.00	-
Reader	0.11	0.31	0	1.00	-
Professor	0.33	0.47	0	1.00	-
Age	21.42	10.45	3	53.00	-
Success	6.05	10.73	0	308.00	+/-
Dept_staff	132.95	58.89	11	271.00	+
Dept_publications	281.62	206.22	8	717.00	+
share of professors in dept	0.30	0.08	0	0.46	+
share of publications by professors in dept	0.49	0.12	0	1.00	+
Niche department	0.05	0.21	0	1.00	-
Thematic mobility of professors in dept	0.36	0.03	0	0.40	+
Job mobile researchers	0.18	0.38	0	1.00	+
Industry contact	0.33	0.47	0	1.00	+
EPSRC grant	0.52	0.50	0	1.00	
Inventor	0.19	0.39	0	1.00	+
Publications	1.66	2.21	0	28.67	

Co-authors	1.86	1.53	0	16.67	
Electrical & Electronic	0.21	0.40	0	1.00	
Mechanical Engineering	0.20	0.40	0	1.00	
Computer Science	0.14	0.35	0	1.00	-
Chemical Engineering	0.17	0.38	0	1.00	
Civil Engineering	0.19	0.39	0	1.00	
Material Science	0.09	0.28	0	1.00	-

Table 3 GLM regression of thematic mobility

	Coef.	SE.
Lecturer (reference)		
Senior Lecturer	0.060**	(0.029)
Reader	0.095***	(0.034)
Professor	0.069**	(0.033)
Age	-0.001	(0.001)
Ln(Success+1)	0.153***	(0.036)
Ln(Success+1)^2	-0.030***	(0.010)
Ln(Dept_staff)	-0.134	(0.110)
Ln(Dept_publications)	0.364*	(0.213)
Ln(Dept_publications)^2	-0.026	(0.023)
share of professors in dept	0.376	(0.472)
share of publications by professors in dept	-0.034	(0.210)
Niche department	0.081**	(0.040)
Thematic mobility of professors in dept	-0.619	(0.853)
Job mobile researcher	-0.037	(0.025)
Industry contact	-0.065***	(0.024)
EPSRC grant	0.095***	(0.025)
Inventor	0.009	(0.022)
Electrical & Electronic (reference)		
Mechanical Engineering	0.118***	(0.028)
Computer Science	-0.087**	(0.034)
Chemical Engineering	0.098***	(0.029)
Civil Engineering	0.091***	(0.030)
Material Science	-0.286***	(0.038)
Ln(publications+1)	0.100	(0.076)
Ln(publications+1)^2	-0.053*	(0.028)
Ln(coauthors+1)	0.248***	(0.081)
Ln(coauthors+1)^2	-0.043	(0.034)
_cons	-2.392***	(0.718)
University Fixed Effect	Yes	
Year Fixed Effect	Yes	
N	3408	
df_m	84.000	
Ll	-1205.131	

Clustered standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01
Observation period differs between researchers and is controlled for.