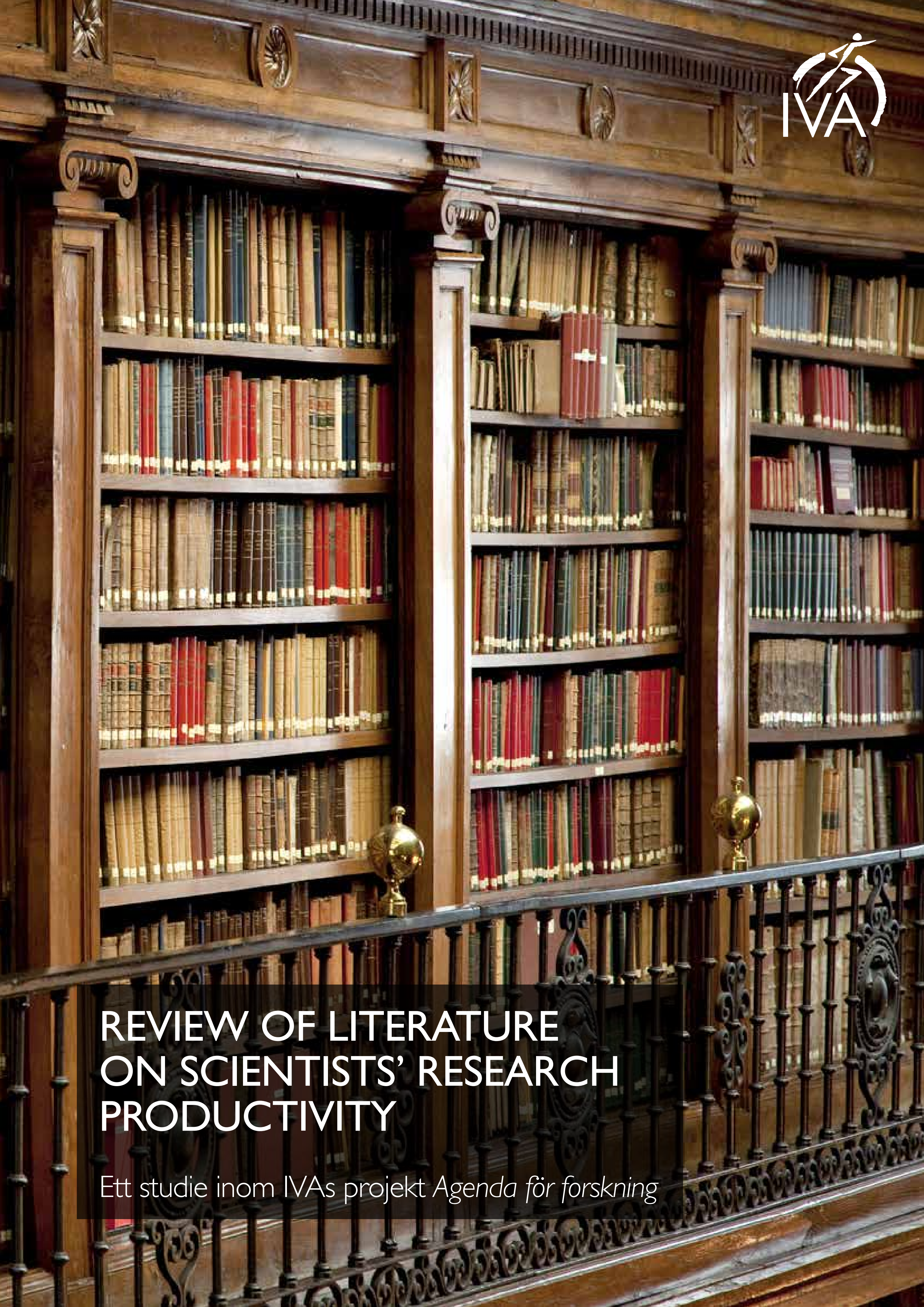

REVIEW OF LITERATURE ON SCIENTISTS' RESEARCH PRODUCTIVITY

Ett studie inom IVAs projekt *Agenda för forskning*

KUNGL. INGENJÖRSVETENSKAPSAKADEMIEN (IVA)
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Review of literature on scientists' research productivity

Summary

1. How is research productivity related to the phases of a research career?
Researchers' scientific productivity increases as they attain higher academic position. Two other individual-level factors are also consistently found to be related to research productivity: researchers' age (curvilinear relationship) and education background

2. Which research-group level factors affect individuals' careers and research productivity?
Scientists backed up by many PhD-students/assistants/technicians are more productive. Group leader's experience and status along with strong leadership and good atmosphere is positively related to individuals' productivity. Larger group size is, at least in natural sciences, also positively related to productivity.

3. How is group composition and resources of PhD-students research groups related to their future careers?
I have not been able to find much relevant previous research on PhD students specifically. Most of the studies have focused on researchers in general and this is reviewed below.

4. Can research productivity, seen in relation to total resources for research, be increased by having resources redirected from PhD-students to senior researchers and to technical/administrative personnel?
I have not been able to find much relevant previous research on this issue. However, one can make some deductions from previous findings. It is well established that PhD students are much less productive in terms of number of publications than more established researchers. Moreover, supervising of PhD students may be time-consuming for the professors. Thus, hiring more experienced researchers instead of PhD students is likely to contribute to improved productivity of a research group. Nevertheless, PhD students are important work force in the science system and do a lot of the time-consuming experimental work. More of this work would then have to be done by the experienced researchers themselves, which will reduce their publication output. This is also confirmed in previous research: Professors with many PhD students are more productive than professors with few PhD-students.

Research productivity: a skewed game

It is well established that there are large differences in productivity between scientists: a relatively small proportion of scientists contribute to the majority of the publications. In 1926 Lotka formulated his famous inverse square law of productivity, which states that the number of authors producing n papers is approximately $1/n^2$ of those producing one (Lotka, 1926). This means, for example, that of all authors in a given field, 60 per cent will have produced just one publication. The results of several later studies have, however, shown that productivity differences in scientific publishing are less than indicated by Lotka, and that Lotka's law overestimates the number of papers produced by the most prolific scientists. Nevertheless, there exists a highly skewed pattern of productivity in scientific publishing (Kyvik, 1991).

Citation distributions are even more skewed. This skewness was early identified by Solla Price (Price, 1965). The large majority of the scientific papers are never or seldom cited in the subsequent scientific literature. On the other hand some papers have an extremely large number of citations (Garfield, 1990; Seglen, 1992). This skewness can be found at most levels of analyses, including individuals.

The skewness pattern of productivity and citation distributions has the implication that the average productivity and citation rates of individuals will be significantly influence by a minority of prolific or highly cited persons. Nevertheless, average scientific productivity and citation rates show large variations across variables such age, gender, academic position and field.

Evaluations of research performance show that there may be large differences between groups, departments, and institutions. This raise the question of what accounts for performance differences. A wide range of possible determinants of research performance have been suggested. It has been shown that the productivity of publications per person may depends on various factors such as gender, age academic position and rank, availability of research funds, teaching loads, equipment, research assistants, workload policies, department culture and working conditions, size of department and organizational context (Dundar & Lewis, 1998; Kyvik, 1993; Ramesh & Singh, 1998). The majority of these studies are correlational in approach. In this review we will look at some of these factors.

Scientific position

Many studies have shown that the productivity of publications at individual levels tends to increase within the hierarchy of academic positions (Bordons et al., 2003; Kyvik, 1991), where professors are the most prolific personnel. A large-scale study by Aksnes et al. (2011) also showed that the professors are by far the most productive persons. On average, male professors published 9.5 publications during a four year period. Next followed associate professors (4.8 publications), post doctors (4.5 publications) while the PhD students had the lowest productivity (2.9 publications). Similar pattern were found for female researchers. However, the average productivity of publications is lower for women than in all categories.

Kyvik (1991) examined four factors that may explain the differences between position categories:

1. There are differences in abilities for doing research between position groups
2. The higher the rank, the more time used for research
3. The higher the rank the easier it is to obtain funding and assistance for research
4. Professors have closer ties to the informal communication network in science than the other groups

Kyvik argues that all factors are likely to contribute to the observed productivity differences. In addition there is a cumulative advantage effect which means that a cumlulative advantage process takes place where those who have the most resources and receive most recognition for the work are the most productive ones.

Another factor is related to the organization of the research system. A professor may have a large research group consisting of several PhD-students, post doctors and other researchers. The professor will be involved in the planning and leading of the research project, but most of the work will be carried out by other members of the groups such as the PhD students. The professor will get his name on all publications produced by the group, while the PhD students will be authors of the publications they directly have been involved in only.

In terms of citation rates there are smaller differences between the various academic positions. The study of Aksnes et al. (2011) found that for both men and women the associate professors obtain the lowest citation rates (field normalized) and the postdocs the highest. Despite the high productivity level of the professors, they did not rank at the top in terms of citation rates. This is interesting as the professors also have attained the highest academic rank and have more recognition and reputation in the scientific community. It is, nevertheless, clear that there is a kind of achievement also in obtaining post-doctoral positions. Usually, only the more successful or able PhD candidates will receive a post-doctoral grant. Moreover, these temporary positions are based on a selection process where the research proposals are carefully examined by peers. It might be that this process secures a higher scientific standard of the research. The associate professors obtained the lowest citation rates of all groups of scientific personnel. This group consists of variety of individuals, ranging from persons who recently have obtained their PhDs to persons who have worked as associate professors for decades without being able to qualify for a full-professorship. Thus, in this group we also find persons who have had less success as researchers, and this might be a reason for the low citation rate.

Age

One question that has been addressed in many papers is the relationship between publication productivity and age. Although the results of previous studies have not always been entirely consistent, it seems to be quite firmly established that there is a curvilinear relationship between age and productivity. The average production of publication increases with age and reaches a peak at some point during the career and then declines (see e.g. (Barjak, 2006; Cole, 1979; Gonzalez-Brambila & Veloso, 2007; Kyvik, 1990). The pattern has been found across many fields and nations. A recent large-scale study which confirms these previous results is (Dag W. Aksnes, Kristoffer Rorstad, Fredrik Piro, & Gunnar Sivertsen, 2011). Compared to many previous studies, typically involving a few hundred persons, the results of this macro-study can be considered to have a high degree of reliability. The study shows that the productivity measured in terms of annual number of publications is increasing by age, reaching a peak late in the career, and declining thereafter. The highest productivity number is found for the 50–54 and 55–59 age groups. Overall, the study showed that the age productivity differences are very large – for example, while persons between 30 and 35 years old published 1.2 article equivalents per year, the corresponding number for the 55–64 age groups was 3.8.

Another issue involves the relationship between age and the quality, significance and impact of the research. A traditional assumption has been that science is a "young man's game" where the best work is done at a comparatively young age (Merton & Zuckerman, 1973). Already in 1953 Lehman in a classical study found that the most important discoveries tended to made by younger rather than older scientists (Lehman, 1953). Lehman concluded that the majority of scientists are most creative when they are in their late thirties or early forties. The study of Lehman has been shown to be flawed methodologically (Cole, 1979). Nevertheless, some later studies have supported Lehman's findings. Most of these studies have used various citation indicators as measures for scientific contribution. Other approaches such as analyses of the age of Nobel Prize winners (Stephan & Levin, 1993) have also been presented and supported the prevailing view on age differences in scientific achievements.

An examination of the literature on the relation between age and scientific performance does however reveal that the results are not consistent. While some studies have reported a negative association between age and citation rates, others have found different patterns. In a recent study of Spanish academics in three scientific areas, Costas et al. found that citation rates declined steadily by age and that persons under 40 have the highest citation rates per publication (Costas, van Leeuwen, & Bordons, 2010). Others studies have found the relationship to be curvilinear. For example, analyzing academics in various academic fields Stephen Cole (Cole, 1979) reported that the overall citation rate was highest for persons between the ages of 40 and 44. Similarly, a study of Mexican scientists revealed a corresponding pattern, but with a delayed peak reached when the researchers were 56 years old (Gonzalez-Brambila & Veloso, 2007). A very different relationship was reported by Gingras et al. who in an analysis of Canadian researchers found an U-shape curve where the citation rates declined for persons between 28 to 50 and then increased until about 70 (Gingras et al., 2008). Other studies, however, have not found any evidence of age specificity in scientific impact. For example, Over (1988) reported that articles in Psychological Review published by older authors were overall cited as frequently as articles published by younger authors (Over, 1988).

The above-mentioned study by Aksnes et al. (2011) also analyzed the citation rates by age. Generally, this study found that citation rates show much less variations by age than do productivity of publications. For the young and middle aged scientific personnel the citation rate was quite stable, and in contrast to the productivity rates they did not find a curvilinear pattern. The most notable finding of the study was that citation rates tend to decline towards the end of the scientific career where persons above 60 are significantly less cited than their younger colleagues. Moreover, the proportion of highly cited persons was highest for the younger persons and declines by age.

Kyvik (1991) has argued that "there seems to be a rather widespread opinion that older scientists are unproductive or out of touch with research frontiers. Gerontocratization of the university faculties has been a common concept – and one with negative connotations" (p. 154). Aksnes et al. (2011) argue that there is some support for this opinion in their study. The fact that the oldest persons have the lowest citation rates and there are few highly cited older persons might be interpreted as indicating that some of these persons are out of touch with the research frontier, are occupied with yesterday's problems and out-dated methods, etc. Still it needs to be emphasized that citations have many limitations as measures of scientific contribution (Aksnes, 2006) and can only provide indications for drawing such conclusions. It is also important to stress that these findings holds for the aggregate. At individual levels that are very large variations both in the productivity and citation rates.

Gender

Many studies have shown large gender differences in scientific productivity ((Dag W Aksnes et al., 2011; Kyvik & Teigen, 1996), where female researcher are less productive. For example, Aksnes et al found that for almost all age groups and domains men are more prolific than women. Female scientists tend to publish generally between 20–40 per cent fewer publications than their male colleagues.

Other individual factors

Individual productivity may be affected by personal research motivation and creativy, abilities and IQ. This issue is not reviewed here. But it is worth mentioning that the educational background has been shown to be important in some studies. (Buchmueller, Dominitz, & Hansen, 1999) found that graduates from top schools, with research assistance expericences and employed in research universities, are more productive than other researchers. Similarly (Turner & Mairesse, 2003) found that Graduates form Grande Ecoles are more productive.

Availability of resources and productivity

One can distinguish between two kinds of resources: financial support for research and research assistance/ human resources such as PhD students and technicians. Concerning the latter: Scientists who have many PhD students/master students/technicians will be more productive in publishing than others. First this is due to the fact that the students and technicians will do much of the time consuming data collection and data analysis work. Second, supervisors may become coauthor of publications mainly written by graduate students and research associates (Kyvik 1991).

Organizational context

It is commonly believed that good scientific environments stimulate productivity and several studies have shown that the productivity of scientists is influenced by the environment. Organisational context can influence on whether a person has possibilities to turn into a productive scientists or whether a research group will flourish or not. However, the issue is difficult to address methodology as it is difficult to judge whether there is a casual relationship between productivity and organizational context. For example, does institutional affiliation affect the productivity of an individual, or is it the productive individual who is attracted by these institutions? One explanation may be that the best departments or groups generally encourage and stimulate the productivity of newcomers, often through collaboration with a successful mentor.

According to Smeby & Try (2005) The contextual factors have greatest impact on the indicator that is considered to be most essential when assessing research performance: published scientific articles. Department climate, age structure, as well as proportion of faculty members' with PhD's have significant impact on research output.

Research has garnered support for departemental prestige as important, less in known about how prestigious departments and units foster, and less prestigious discourage, publication (Fox, 1983). Long & McGinnis (1981) report that the effect of productivity upon prestige is weak, but the effect of location upon productivity is strong. He found that for scientists moving into first academic position, publication level is not immediately affected by the prestige of the new department; rather, productivity levels are affected by early (that is, pre-doctoral) publications – for a while. However after third year in appointment, scientists' productivity is more strongly affected by prestige of their present location, than by their predoctoral publication – so that those in prestigious department increase their publication while those in less prestigious departments publish less.

Long & McGinnis (1981) found in a study of US scientists that the level of productivity conformed with the publication characteristics of the unit: Within 3 to 6 years of obtaining a position, a scientist's level of productivity conforms with the characteristics of the unit, independent of previous productivity.

Stankiewich found that in Swedish research groups in science and technology which are led by young and inexperienced scientists productivity is lower than in groups where leaders are experienced scientists (Stankiewicz, 1979).

An Australian study found that certain kind of departemental context may lead to higher productivity. In particular academic units that are cooperatively managed, together with a sense of satisfaction rather than alienation from the work environment, was likely to result in higher level of individual productivity (Ramsden, 1994).

Other studies have looked at organisational freedom as it influences productivity. While the findings are somewhat mixed, they tend to suggest that higher level of freedom support publication productivity (Fox, 1983).

Other variables have found to be at least correlated with research performance. These factors have included amount of research spending, number of students at the department, and the percentage of faculty holding a research grant (e.g. Gruning 1997). Workload policies may be important.

Another issue is department size: (Kyvik, 1995) identified several arguments in favour of larger departemental size: First, larger departments can better facilitates collaborative research groups. Second, larger departments are more likely to attract high quality researchers. Third, larger departments have greater amount of resources. However, the results of the research on faculty size are mixed. In his study Kyvik reported no significant relationship between size and research productivity except in the natural sciences. There are also other results which show no relationship between size and productivity and the majority verdict seems to be that research output is linearly related to size with no significant effect of scale apparent. However, others, such as (Dundar & Lewis, 1998) found that academic productivity was related to faculty size. However, with a diminishing rate. At a certain level the marginal product of one extra faculty will start to decline. Some previous studies have also noted that the research productivity to some extent is a result of critical mass. They also found that having more full professors, having a larger percentage og department faculty working on research and having more "star professors" all contributed to enhanced productivity. One possible reason for the difference in previous studies may be that different studies have focused on different units of analysis: research groups, departments and entire institutions. It may be that the relationship between size and performance depends on the unit of analysis chosen.

Conclusion

The picture that emerges of the causes of productivity is complex. There are clearly many interacting factors that contribute to research productivity. Research group size or access to resources is just one, which on the evidence available, may not be very important. Explanations of research performance must take into account personal (individual) and structural (environmental factors), and the interaction between them.

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