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Excessive Accumulation of Knowledge as a Challenge to Science Policy

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Abstract: *In response to current economic theories, a special emphasis is put on the need for continuous acquisition of knowledge. The stock of knowledge, however, is growing very dynamically, which leads to shifts in the scientific process. There are shifts in individual innovative productivity, which is manifested by the fact that the contribution of young scientists to science is getting smaller and – as a result of deepening of specialization – the dominance of teamwork increases. These two fundamental changes taking place in science should imply changes in the approach to science policy.*

In the face of "ageing" of innovators, policy makers should put more emphasis on creating incentives for young people to enter scientific careers (higher wages in science, more attractive grants at the peak of scientific career; contrary to popular beliefs, grant systems should not be created specifically for young people). A measure increasing the interest in scientific careers could also be a shortening of education which, however, is difficult to achieve.

A response of science policy to the increasing dominance of teamwork should be (1) implementation of changes in the remuneration system for researchers, which should evolve from individual-oriented rewarding to team-oriented reward-

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ing, as well as (2) implementation of changes in the evaluation system, which should be aimed towards team evaluation.

Introduction

Since endogenous growth theory was formulated, increasing attention has been paid to problems of broadly conceived knowledge, as it has been recognized as the most important factor in the economic growth of a country. In light of the above theoretical findings, special emphasis has been placed on the need to acquire knowledge.

There are voices in the literature, however, that the steadily expanding stocks of knowledge result in shifts in the scientific process, including also negative developments, which in turn should lead to changes in the approach to science policy.

The purpose of this article is to show the fundamental changes in science that occur as a result of excessive supply of knowledge, as well as indicate directions in which – in the face of these changes – science policy should evolve.

Oversupply of knowledge: a research approach

Measurement of the size of knowledge and, even more so, the excess of knowledge involves many difficulties. They result mainly from the fact that knowledge is an abstract concept, it is intangible. Moreover, it is not known what the optimum knowledge stock is for a given country or region, and thus it is actually a relative matter whether we are dealing with an excess or deficiency of knowledge. In spite of those difficulties, knowledge oversupply estimation methods can be found in the literature, although they only take the form of claims that „there is too much knowledge" rather than specific estimates of the volume of "useless knowledge".

The researchers dealing with problems of knowledge excess are convinced that excessive accumulation of knowledge can be "harmful" in certain circumstances. As a consequence, they estimate only the size of negative (in their opinion) effects of knowledge oversupply, which means that the measurement of knowledge excess is indirect and largely based on assumptions.

One of such negative effects related to excessive accumulation of knowledge that is indicated in literature is „aging of innovators", which means e.g. that every new generation of innovators make their first breakthrough discovery (accomplishment) being older than the preceding generations (this and other negative consequences of knowledge excess are discussed in more detail in the next section of the article). Therefore, if a researcher wants to show that we face an excess of knowledge, then they must show, among other things, that „aging of innovators" takes place, i.e. show e.g. that over time every new generation of Nobel Prize winners or scientists whose names lie at the origin of a theory or other selected group of „prominent" innovators are older at the time of obtaining their doctorates, creating Nobel Prize-winning ideas or other accomplishments. If the research results indicate „aging of innovators", it is partly concluded on this basis of the fact that there is a phenomenon of excessive accumulation of knowledge. In order to increase the certainty that excessive knowledge is the cause of „aging of innovators", an analogous study should be conducted on a control sample, e.g. on outstanding athletes, whose achievements are not based on knowledge. If it is found that the greatest, first achievements of successive generations of athletes are made at the same or even younger age, it would mean that among athletes, whose work is not based on knowledge, the phenomenon of „aging" does not occur. This would additionally strengthen the hypothesis that individuals whose work is based on knowledge may be sometimes disturbed by its excess.

In this article, in-depth and critical literature studies have been conducted. The conclusions have been formulated on the basis of the literature, especially articles in reviewed journals, focusing mainly on the problems connected with negative effects of excessive stocks of knowledge.

Basic trends in science as a result of excessive accumulation of knowledge

Today, researchers (innovators) are forced to be educated and create their ideas on somewhat different terms than their predecessors did 50 or 100 years ago. First of all, they face stocks of knowledge that increase every year, a kind of accumulation of knowledge. It is estimated, for instance, that average annual publication growth rate (Web of Science) is 5.5% (Jones, 2010b, p. 1). These changing creative work conditions, in turn, imply further changes.

Excessive amounts of knowledge stocks result, among other things, in changes in individual innovative productivity. The first ones to have indicated the presence of this phenomenon were Hall, Jaffe and Trajtenberg (2001), those authors however did not indicate its causes. They have shown that the age of researchers at the time of their first invention rises over time at a significant rate, which means that innovators in every new generation are older. Similarly, Moore *et al*. have shown that the average age of researchers who receive their first grant has risen (Moore *et al*., 2009).

Similar observations have been made by Jones, too, who extended conclusions of Hall *et al*. and also indicated the source of changes in innovative productivity. Jones (2009, 2010a), on the basis of studies he conducted, has shown that (1) successive generations of innovators start knowledge-based careers increasingly later, (2) the first great accomplishments based on knowledge (in science) are generated by increasingly older inventors[1], (3) innovative life output of successive generations of innovators is getting smaller and (4) the period in lives of successive generations of innovators in which they are productive is getting shorter[2].

According to Jones, the role of the individual in science is changing because of excessive knowledge accumulation and deepening of its fields, and more specifically, because of the fact that every new generation of innovators increasingly larger amounts of knowledge.

Jones argues that investment in human capital is an indispensable factor of innovative activities. Therefore, every new generation, if it wants to increase its innovative potential and innovate, i.e. „make its step forward", must first possess the old knowledge, that of its predecessors. The acquisition of knowledge, however, is costly as it is connected with the necessity to sacrifice a certain part of one's life (the more knowledge one wants to possess, the more of one's life one must sacrifice). Therefore, every new generation must acquire more knowledge in order to make their first breakthrough discovery, which means that they must learn increasingly longer. Hence the marginal capacity to innovate decreases (Niklewicz-Pijaczyńska & Wachowska, 2012, pp. 116-119), i.e. generating of innovations by suc-

[1] The first great accomplishment of an innovator is often difficult to clearly identify since it is usually a subjective matter. If e.g. innovative productivity of Nobel Prize winners (as the most prominent innovators) is studied than it is assumed that the first great invention is the one for which the innovator has received the Prize. In turn, in the case of innovators not being university researchers, the first great finding can be assumed to be the first idea of the innovator that was protected by a patent.

[2] Measurement of productivity of innovative activity is difficult because there is no single measure of productivity. In the case of innovators – academic researchers, the most common measures of productivity are SSCI measured citations, as well as the number of papers and books published.

cessive generations becomes increasingly difficult in the sense that in lasts increasingly longer.

Since the process of learning becomes increasingly longer, i.e. successive generations of innovators start their knowledge-based careers later in life, and biological processes cannot be stopped, the period in the lives of successive generations of innovators in which they are productive is getting shorter. Moreover, since innovators start their careers increasingly later, and the research potential of innovators is the largest in their youth (which they sacrifice for learning to a large extent), excessive accumulation of knowledge reduces in a way, *ceteris paribus*, the inventive product of the whole life of successive generations of innovators.

The Jones' studies are continued by the studies of Jones and Weinberg (2011), whose subject was an analysis of age dynamics of scientists from areas of the so-called hard sciences (Physics, Chemistry, Medicine) at the moment of their breakthrough discoveries. In this case, the authors indicated, like they did before, the occurrence of shifts in individual innovative productivity towards the ageing of innovators. In particular, these shifts relate to the area of Physics, in the case of which the average age of the scientist at the moment she or he produced a breakthrough idea increased by 13.4 years over the course of the whole research period (1901-2008) (Jones, Weinberg 2011, p. 18910). Slightly smaller shifts have been observed in Medicine (7.4 years) and Chemistry (10.2 years), however they are significant in these areas as well (Jones & Weinberg, 2011, p. 18910). The analysis by Jones and Weinberg indicates that the phenomenon of ageing of innovators is common and cannot be explained by differences in particular fields of science.

Deo *et al.* (2012) also document the decreasing contribution of the young to science from year to year, but in their opinion it is a result of reduced number of workplaces available for young scientists in the area of R&D.

Since Deo *et al*. (2012) provided neither theoretical nor empirical evidence in support of their considerations concerning the causes of aging of innovators, otherwise than Jones and Jones *et al*., excessive amount of knowledge that extends the process of education continues to be the most probable explanation (proposed by Jones) for the occurrence of shifts in individual innovative productivity.

An alternative to the spending of increasing number years of one's life on education is to narrow one's area of expertise, which limits the amount of knowledge needed to be acquired. However, the education oriented towards deeper specialization reduces the individual's ability to independent creation of ideas, thus in a way eliminating innovators of the „renaissance man" type and forcing them into teamwork (e.g. Malone, 1995). Moreover, the deeper the knowledge, the greater the need to cooperate with others.

The existence of the trend towards cooperation is suggested e.g. by the studies by Teasley and Wolinsky (2001) and Ding *et al.* (2009), who see the sources of this phenomenon in modern technology which makes "barriers of distance" between collaborators located far apart disappear. The increase in cooperation between researchers from different universities is indicated also by Jones, Wuchty and Uzzy, wherein – contrary to their predecessors – they exclude the possibility of the cooperation being driven mainly by modern communication technologies (Wuchty *et al.*, 2007; Jones *et al.*, 2008). The results of studies by Wuchty *et al.* indicate the increasing dominance of research teams in generation of knowledge in all areas of science (natural, technical, social sciences, humanities). Their continuation confirms the existence of the above mentioned tendency. Namely, the analysis by Jones *et al.* shows that both the number of research teams as well as the frequency of cooperation between researchers from 662 major U.S. universities has been on the rise since 1975, and the growth rate of the cooperation is generally constant over the whole research period (1975-2005). Only in 1998, when Internet and other technologies began to proliferate, a higher rate of increase in cooperation was recorded, yet later it returned to the one from the period before 1998. This proves, according to Jones *et al.*, that the inter-university cooperation is driven by other factors than communication technologies.

The shift towards teamwork may be therefore considered as another change observed in science that results from excessive accumulation of knowledge.

Science policy implications of diminishing innovative products of young scientists

The extended education period and perspective of creating the breakthrough idea later in life discourage starting of scientific careers. This stems from the fact that receipt of rewards expected by an individual is delayed, i.e. for example, value of grants, status or joy of creation and creative freedom (Stern, 2004).

As a result of this, individuals, instead of choosing scientific careers in which a doctorate is earned at an increasingly older age[3] and postdoctoral

[3] The analysis of Nobel Prize winners' (as being among the most prominent innovators) age on the day of their receiving their doctorate supports the thesis that researchers receive their doctorates at an increasingly older age (Jones, 2010a).

phases become extended (it concerns especially such areas as Biotechnology or other so-called experimental sciences), may opt for careers requiring less involvement in training and in which a stream of high wages is obtained relatively quickly. The effects of such a choice may be especially severe for science, scientific progress, and consequently also for economic growth when science is avoided by exceptionally talented individuals.

Therefore science policy faces a challenge to provide incentives to start careers in science and research, especially the basic research.

The most obvious incentive are wages. If they were to perform the function of attracting – especially the most talented individuals – to scientific careers, then they should be on a level which would compensate for each additional year of training and also surpass the levels offered by other careers.

Alternatively, longer, larger (especially in the wage part) and less restrictive research grants should be offered in the peak period of scientific career in order to be an incentive for young researchers who are still in their training period (Jones, 2010b, p. 21).

Another alternative is supporting young researchers with grants addressed especially to them (Jones, 2010b, pp. 21, 25). If we assume, however, that there is a phenomenon of excessive accumulation of knowledge which makes generation of important ideas by researchers in young age less likely, then offering grant money to the young is ineffective and in a sense unethical. This is because a young researcher will get support for realization of their project (with little innovative potential) at the expense of a (significant) project created by an experienced researcher. However, if the young researcher, contrary to theories and results of empirical analyses, created a breakthrough idea then they could freely apply for grant support together with other researchers, including the elder ones. Therefore, there is no justification for creating a special grant offer exclusively for young researchers.

In literature, one can also be find a view according to which support for the young should come only from the wage part (Jones, 2010b, p. 21) in order to highlight, in a way, that the project itself is of little meaning and that the research proposed by the young researcher can be conducted without the use of financial means. In such a case, however, it seems more effective and honest to pay wages to all the young as a compensation for the unproductive period when they are acquiring education than to engage public funds in administrative service of grants, including also remunerating experts to review the research projects.

An additional possibility, which might contribute to an increase in interest in scientific careers is acceleration of training (Jones, 2010b, pp. 21-22). It is probably the best alternative, since human beings are most creative and have the greatest innovative potential in youth (Levin & Stephan, 1991; Stephan & Levin, 1993; van Dalen, 1999).

In response to those discoveries, science policy should place more emphasis on early separation of educative paths of future scientists and other people in order to ensure that future innovators receive training which is more intensive and better quality, as well as shorter (Jones, 2010b, pp. 21-22).

The above alternative, however, is difficult to realize for many reasons. Firstly, who and according to what criteria would be to decide which children have the potential to become scientists in the future. Secondly, even if correct selection of children were made, do adults have the right to decide for children who they will be in the future? And finally, the possibility for significant intensification of education does not seem very probable, even among children and youth with potential for future creative work.

Science policy implications of shift towards teamwork

As it has already been mentioned, the researcher is increasingly forced to deepen specialization and teamwork as a result of increasing stock of knowledge. Meanwhile, the remuneration system in science seems to be inconsistent with this trend. The most important prizes in science, i.e. the Nobel Prize or Fields Medal, are predominantly awarded for individual achievements. Even prizes of decidedly little importance are oriented towards the individual. Namely, (e.g. in Poland), in a research team that is applying or has already obtained a grant to fund its project, only one person can be the project manager (even if the idea of the project is a fruit of work of more than one person) and it is mainly she or he who enjoys all honors.

Rewarding individuals at the expense of the team raises a number of issues (Jones, 2010b, pp. 25-28). Firstly, it encourages rather individual work and hiding of ideas, which in consequence is detrimental to science and economy, since diffusion of knowledge occurs to a lesser extent. Secondly, by blurring recognition, it discourages engagement in teamwork, which – in the case of a well selected team – is more effective and results in creation of more groundbreaking ideas than individual work. Thirdly, it may turn out that when choosing partners for cooperation, researchers look at who in the team has a chance to become its leader. In other words, the researcher will seek to assemble such a team as to become its manager herself or himself. And finally, if the research activity becomes crowned with success, the researchers may become enemies, fighting for recognition and prizes, which is not beneficial for science either.

If we add to this that teamwork is against human nature, as human beings have tendency to do everything by themselves, believing that they themselves will do everything best, and is also connected with additional inconveniences (Jones, 2008) related to finding experts with complementary skills and coordinating with them, then one of the most important science policy tasks should be creating incentives to engage in teamwork.

In this context it seems especially important to move from the system of individual rewards to team prizes in science.

Increasing dominance of teamwork in science should also produce policy responses addressing the system for evaluating ideas in science (Jones, 2010b, pp. 26-27). First of all, it concerns the evaluation of research proposals and commercial inventions.

Proper evaluation of ideas is particularly important as, on the one hand it affects directions of creative effort and the line of research, and on the other hand it is significant for intellectual property rights. When the evaluation mechanism is widely felt to be biased or not very transparent, it may discourage to make an innovative effort. Alternatively, it may encourage making this effort in the direction of such projects which in the opinion of the innovators will „enjoy" special treatment from the evaluators.

The response of science policy to increasing teamwork in generation of ideas should be the transition from the evaluation carried out by a single person to a team of evaluating experts, who would have the potential to assess a research proposal or patent application widely defined by a team of narrowly specialized innovators. In such a case, each expert would evaluate only this specialist knowledge embodied in the research project or patent application which lies within the reach of his own expertise.

It is important that the evaluating teams are appointed flexibly, so that they are able to assess interdisciplinary proposals as well. Moreover, no less important than the "principal" evaluation of an idea is so-called preliminary evaluation, the effect of which is the appointment of an evaluating team suitable for a given research proposal or patent application. It is particularly important in the case of ideas that are „ahead of their time" and may be incomprehensible for the preliminary evaluator. Therefore, the preliminary evaluation should also be made by a team of experts.

Due to the fact that the greatest problems occur at the evaluation of the most groundbreaking ideas, there are postulates that the system of evaluation in science should move towards so-called open evaluation. It consists in evaluation of an idea by all interested „professional colleagues”. Unfortunately, this type of evaluation would mean the necessity for early public disclosure of the research idea, which would rather discourage the innovator to innovative activity.

So far as the principal evaluation of ideas is concerned, both in Poland and globally, it can be noticed that science policy becomes directed towards team evaluation, including also creating flexible teams (in evaluating publications, grants or patent applications, although the latter to the smallest degree). Unfortunately, the system of preliminary evaluation does not seem to keep pace with the above trends, which is indicated e.g. by postulates towards so-called open evaluation. In Poland, meanwhile, it happens that knowledge of the preliminary evaluator of a research idea in grant applications is insufficient, as a result of which she or he is not able to find and appoint an adequate evaluating panel. As a consequence, a part of knowledge embodied in the research project is either not assessed or its assessment is subject to error.

Conclusions

Considerations taken in this article show that each year global stocks of knowledge increase, which means that every new generation of innovators faces increasing educational burden. As a consequence, the role of an individual in science changes. Shifts occur in individual innovative productivity, which manifests itself in the fact that the contribution of young scientists in science is diminishing and – as a result of deepening specialization – the dominance of teamwork is increasing.

These two essential changes taking place in science should imply changes in the approach to science policy.

In the face of „ageing” of innovators, policymakers should place more emphasis on creating incentives for the young to enter careers in science. Such incentives could involve paying sufficiently high wages to scientists or offering them larger and less restrictive research grants in the peak period of their scientific career. Contrary to the popular opinion, however, creating a grant offer addressed especially to the young seems not very effective. Another measure that would increase interest in scientific careers could be reduced time of education, which is however difficult to realize.

Science policy should respond to the increasing dominance of teamwork by (1) implementation of changes in the reward system for scientists, which should evolve from individual-oriented to team-oriented rewarding as well as (2) implementation of changes in the system of evaluation, which should move towards team evaluation.

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