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Optimal distribution of science funding

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HIGHLIGHTS

- The model explores a new funding scheme and optimal distribution.
- The model has five parameters.
- Three distinct regimes were observed.
- Concentration can only be suppressed in regime (I).

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ABSTRACT

We propose a new model to investigate the theoretical implications of a novel funding system. We introduce new parameters to model the accumulated advantage. We assume that all scientists are equal and follow the same regulations. The model presents three distinct regimes. In regime (I), the fluidity of funding is significant. The funding distribution is continuous. The concentration of funding is effectively suppressed. In both regimes (II) and (III), a small group of scientists emerges as a circle of elites. Large funding is acquired by a small number of scientists.

1. Introduction

Science funding is important both to support and to reward scientists for conducting good research. In practice, funding agencies have their own goals and follow their own policies to allocate the grants. The funding distributions can be very different for different agencies. It is interesting to ask whether there is an optimal result of funding allocation. The concentration of funding has been a general tendency [1,2]. A minority of scientists receive the majority of funding. Regarding to the impact of funding concentration, the evidence is mixed. It is known that cumulative advantage is behind the practice of science [3,4]. Many studies indicate that science funding has a positive effect on the research productivity [5–8]. Thus, it is reasonable to allocate more funding to support the best scientists. On the other hand, more recent studies show that increasing the funding leads to decreasing marginal return [9,10]. It is then suggested to refrain from allocating more funding to reward the scientists for the past achievement.

Concentration of funding also has other drawbacks. Larger grants are awarded to fewer projects. Preparing the research proposal becomes much more time-consuming. A low approval rate implies not only an intense competition but also a waste of time in writing proposals for most scientists. As the competition intensified, the review process will require much more rigour and become much more time-consuming. With the emphasis of peer review and ethical implications, the concentration of work load can be expected. Even for those few projects got approved of large grants, more time spare to the administrative work implies less time to do research. The structural problems in funding system has been raised by many studies [11–17]. Alternative approaches are then proposed [18–20].

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Recently a novel model of science funding was proposed [21]. Compared to the empirical funding distribution, the new system claimed to reproduce a similar result at a fraction of the time and cost of the current system. In contrast to the traditional top-down approach, peer-to-peer opinions are emphasized. The funding circulates fluidly from one scientist to another. The new system could potentially be fairer and more efficient. Instead of decided by a small committee, the new system includes the whole community to allocate the budget. The funding distribution can be the optimal result favoured by the community. It seems that the concentration of funding can be swiftly avoided. In this work, we report a systematic investigation of this novel mechanism. We propose a new model to explore the theoretical implications. The model is introduced in Section 2. The previous study used citation behaviour as a proxy for funding decisions to reproduce the funding distribution of the empirical data. We propose new parametrization to explore the optimal result of funding distribution. The model analysis is presented in Section 3. The concluding remarks are in Section 4.

2. Model

Consider a community of N scientists. The annual research funding allocated to each scientist is denoted as u_i, where $i = 1, 2, 3 \cdots N$. This model explores the theoretical implications of a novel mechanism proposed recently for science funding [21]. The scientists receive funding both from a central agent (e.g., government) and from peer-to-peer donations. Each scientist is supported annually by the government a base funding u_0, which is the same for all scientists. The donations from other scientists depend mainly on the peer opinions. Each scientist is required to donate a part of his/her budget to others and allowed to spend the rest of the budget in his/her own research. Specifically, only a budget $(1-F)\cdot u_i$ is allowed to be used in his/her own research. A budget $F \cdot u_i$ has to redistribute to M others, where F is the ratio of donation and M is the number of donatees. The process of budget allocation is regulated by the two parameters F and M. We further introduce two other parameters to specify the details of budget redistribution. The parameter α controls how to choose the M donatees. For scientist i to choose a donatee, the probability for scientist $j \neq i$ being chosen is proportional to $(u_j)^\alpha$. When $\alpha = 0$, all the scientists are chosen randomly. When $\alpha > 0$, the scientists with more funding will have higher probabilities to receive more donations. The other parameter β controls how to distribute the donation among the M donatees. Once chosen, the donation received by scientist $j \neq i$ is proportional to $(u_j)^\beta$. When $\beta = 0$, the M donatees share the donation equally. When $\beta > 0$, the donatee with more funding has a larger share of the donation. Both $\alpha > 0$ and $\beta > 0$ imply the well-known Matthew effect of cumulative advantage, where the rich get richer and the poor get poorer.

In the numerical simulations, the initial conditions are $u_i = u_0$ for all i. All variables u_i's are updated simultaneously at discrete time steps as follows: $u_i \to u_0 + \sum_{j\neq i} D_{j\to i}$, where $D_{j\to i}$ denotes the donation from scientist j to scientist i. A constraint is imposed as follows: $\sum_{i\neq j} D_{j\to i} = F \cdot u_j$. As the donation $D_{j\to i}$ is proportional to the funding u_i, a recursive relationship is present in the dynamics. The update process repeats until it reaches a stable result. The final distribution of funding is controlled by α and β. When α and β are small, the budget is spread out among all scientists. When α and β are large, the budget is concentrated into a few members of the community. In this model, the annual budget inflow is Nu_0 and the annual spending is $\sum_i (1-F)\cdot u_i$. In the steady states, the funding u_i's have an average value of $u_0/(1-F)$. The minimum value is bounded from below by u_0. The maximum value is then a good indicator to measure the funding difference among scientists. The typical profile of the maximum funding is shown in Fig. 1. The corresponding contour plot is shown in Fig. 2. Three distinct regimes can be observed. In regime (I), α is small and the funding distribution shows a continuous spectrum. The maximum is not much larger than the minimum. As β varies, these is no significant change in the maximum. In both regimes (II) and (III), α is large and the maximum rises discontinuously. The concentration of funding is significant. Most scientists acquire the minimum funding. The large funding has been allocated to a few scientists. In regime (II), where β is small, a group of $(M + 1)$ scientists share the entire funding. The maximum becomes $u_0NF/(1 - F)/(M + 1)$. In regime (III), where β are large, the entire funding is divided by only two scientists. The maximum rises further to $u_0NF/(1 - F)/2$. The rank distributions of u_i's in these three regimes are shown in Fig. 3.

3. Discussions

The previous study showed that the empirical funding distribution can be well reproduced by this novel mechanism [21], where choosing the donatee and distributing the donation are determined by the citation network. In this study, the citation network has been replaced by a random process controlled by two parameters α and β. The same results can be obtained. From the perspective of individuals, the bibliography of each publication is deliberately compiled and far from random. From the perspective of community, however, each reference list is independent to others and thus can be well represented by a random process. The accumulated advantage is presumed in the model. Amount of funding is expected to have a positive correlation with the research output. The continuous distribution in regime (I) provides a reasonable result of funding distribution. When α is small, the variation of β does not lead to significant change. When the donatees are chosen randomly, the accumulated advantage is minor even if the donations are distributed unevenly. The funding distribution is mainly determined by the parameter F, which controls the scale of redistribution. Typical results are shown in Fig. 4. When F is small, redistribution is limited. The fluctuations of u_i's are small. Only a slight deviation above the default value of u_0 can be observed. When F is large, the fluctuations of u_i's are enhanced. The maximum value of u_i's increases accordingly. In contrast, the parameter M plays a minor role as shown in Fig. 5. As M increases, the fluctuations diminish and the rank distribution becomes flat. Both the first rank (maximum) and the last rank (minimum) approach the average value at $u_0/(1 - F)$. We