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Knowledge spillover processes as complex networks

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HIGHLIGHTS

- We make a model for knowledge spillover as a process on complex networks.
- The economic growth rate is determined by the mean degree of the nearest neighbors, not by the mean degree of the network.
- The more heterogeneous the network is, the greater the growth rate is.
- The growth rate is the largest in scale-free networks and the least in regular networks.

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ABSTRACT

We introduce the model of knowledge spillover on networks. Knowledge spillover is a major source of economic growth; and is a representative externality in economic phenomena. We show that the model has the following four characteristics: (1) the long-run growth rate is not relevant to the mean degree, but is determined by the mean degree of the nearest neighbors; (2) the productivity level of a firm is proportional to the degree of the firm; (3) the long-run growth rate increases with the increasing heterogeneity of the network; and (4) of three representative networks, the largest growth rate is in scale-free networks and the least in regular networks.

1. General question and introduction

1.1. General question

Knowledge is the most important and representative externality in economics. The spillover of knowledge has a significant effect on economic growth and the productivity of an individual firm. The spillover process among firms can be represented as a process on complex networks. In the present paper, we study how the underlying network structure affects the growth. For this purpose, we introduce an equation that describes the knowledge spillover process on complex networks. We determine the kind of network that gives rise to a high growth rate and productivity. The motivation comes from network studies. The knowledge spillover is a significant positive externality in economics, and the externality can be studied by the method of networks. People in networks must study spillover more. Probably, it is fruitful.

1.2. Introduction

Growth theories have shown that the progress of technology determines long-run growth. Most previous papers focused on the research and development (R&D) activities (Refs. [1–5]). Although R&D significantly influences economic growth,

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knowledge spillover also has a considerable effect. It is occasionally assumed in the literature that once new technology is invented, it spreads immediately across the world at no cost. On the contrary, technology diffusion takes significant time and incurs various costs. Ref. [6] raised a relevant example: the use of the water mill took a millennium to spread to other areas in pre-medieval and medieval times in Europe possibly because significant mobility was more difficult during those eras.

Refs. [7,8] showed that a more productive type of hybrid corn diffused slowly in the US. The diffusion of a new hybrid seed had a clear spatial pattern. Initially, only a small number of farmers adopted the new seed. Over time, their neighbors adopted them. Later on, the neighbors of the neighbors adopted it, and the same process proceeded over time. Geographical proximity is key to understanding knowledge spillover, and the diffusion process of the technology can be described by the well-known S-curve. The diffusion process of a new hybrid seed described above can be regarded as a process continuing over the social network of farmers.

There is no doubt that technological differences exist across countries and even within a single country. We observe significant differences across firms in even a narrowly defined industry. Ref. [9] showed that technology is local rather than global. This evidence shows that new technology does not spread instantaneously. The knowledge spillover process proceeds over a structure, which can be expressed as a network. Unless such networks existed, it would be difficult to explain why significant technological differences exist and why it takes significant time for new technology to spread.

Managers, engineers, and scientists acquire new information from each other to enhance their productivity. Why are so many firms concentrated in small areas? Similarly why are so many technology firms concentrated in small areas, such as Silicon Valley? This is because firms operating in such areas can easily acquire information from others. Ref. [10] showed that innovations in the late 20th century occurred intensely in the places where universities and firms undergoing R&D were concentrated.

We study knowledge spillover on complex networks and show that network heterogeneity plays a crucial role in the knowledge spillover processes. We focus on the long-run growth rate, which is more important than a short-run one. We show that the essential difference among networks exists in the mean degree of the nearest neighbors and not in the mean degree. The long-run growth rate is determined by the mean degree of the nearest neighbors of the network and, interestingly, not by the mean degree of the network. The long-run growth rate is the same across all firms connected to the network. A heterogeneous network is the network where the variance of the degree distribution function is great. The growth rate increases with the increasing heterogeneity of the network. However, the productivity level of each firm is proportional to the degree.

1.3. References

Ref. [11] studied patent citation data and showed the relationship between collaborative networks and knowledge diffusion. The topology of a patent citation network is studied by Ref. [12]. Ref. [13] studied inventors' networks and found evidence of an agglomeration of investors. An intra-organizational investors' network was studied by Ref. [14]. Ref. [15] showed that the rate of technological progress depends on the number of innovators in the same knowledge network. Reviews [16,17] discussed that geographical relation is an important factor for knowledge spillover. Ref. [18] studied social network of open source software projects. Ref. [19] studied university–industry collaborations. Ref. [20] studied information and knowledge transfer in a sample of 16 German regional innovation networks with almost 300 firms and research organizations involved. Knowledge spillover was reviewed by Ref. [21] in view of urban economics. The knowledge spillover has been studied by Refs. [22–26] in some respect. Our model is different from these previous studies in that the network structure of knowledge spillovers exists, while this focus is absent in previous works. Ref. [27] studied the R&D formation mechanism in which coalition diminishes marginal cost. In this paper, we study an exogenously given knowledge spillover network and investigate how it affects the growth rate. We assume that an exogenously given network is a normal method of studying networks if one studies how a network structure affects an outcome. We mainly focus on how the underlying network structures affect the growth rate. For this purpose, we use an exogenously given network and do not focus on network formation mechanism.

The relation between knowledge spillover and a network has been studied by many other papers theoretically and empirically, such as Refs. [28–41]. All of these papers mentioned that the network has a significant effect on knowledge spillover. Reviews on networks are found in Refs. [6,42–48].

1.4. The mean degree $\langle \xi \rangle$ and the mean degree of the nearest neighbors $\langle \xi_{nn} \rangle$ are different

Before we begin to discuss knowledge spillover, we must show that the mean degree $\langle \xi \rangle$ and the mean degree of the nearest neighbors $\langle \xi_{nn} \rangle$ are to understand the following sections and the core of the mean-field approximation that we will introduce in the next section. Let $\langle x \rangle$ denote the expectation of a random variable x. The mean degree $\langle \xi \rangle$ and the mean degree of the nearest neighbors $\langle \xi_{nn} \rangle$ are illustrated in Fig. 1. The mean degree $\langle \xi \rangle$ is the mean degree of randomly chosen vertices. The mean degree of the nearest neighbors $\langle \xi_{nn} \rangle$ is the mean degree of vertices neighboring randomly chosen vertices. We repeatedly use the fact that the mean degree $\langle \xi \rangle$ is different from the mean degree of the nearest neighbors $\langle \xi_{nn} \rangle$, which plays an important role in models on complex networks. It is this difference that brings interesting phenomena. One might