Physica A 458 (2016) 157–167

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Network effect of knowledge spillover: Scale-free networks stimulate R&D activities and accelerate economic growth

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HIGHLIGHTS

- Knowledge spillover from Research and Development (R&D) activities is studied through knowledge spillover networks.
- How the spillover networks affect R&D investment and economic growth is studied.
- Scale-free networks stimulate R&D and accelerate economic growth.

ARTICLE INFO

Article history:
Received 3 September 2015
Received in revised form 1 April 2016
Available online 20 April 2016

Keywords:
Scale-free networks
Network heterogeneity
Knowledge spillover process
Complex networks
Economic growth
Research and development (R&D)

ABSTRACT

We study how knowledge spillover networks affect research and development (R&D) activities and economic growth. For this purpose, we extend a Schumpeterian growth model to the one on networks that depict the knowledge spillover relationships of R&D. We show that scale-free networks stimulate R&D activities and accelerate economic growth.

1. Introduction

A firm undertakes research and development (R&D) activities to develop an innovative technology. The technology spills over to other firms over time, propagating the knowledge obtained from the R&D activities. The Knowledge spillover is one of the major sources of economic growth [1,2]. In reality, spillovers are likely to diffuse among all the firms across the world simultaneously. As demonstrated by Ref. [3], the spillover process takes a significant amount of time. This process can be presented as a network where in the knowledge transfers to the neighboring firms only at a time. The network depicts the relation spillover occurs in one unit time. In this paper, we study how the network structures depicting the spillovers called R&D spillover networks in this paper affect R&D activities and economic growth. The knowledge obtained from R&D activities propagates over such network to other firms.

The relation between network structure and spillover has attracted much attention from researchers. For example, it has been theoretically and empirically studied by the following papers [4–13]. Several papers also describe on inventors networks [14–20]. These authors show that the underlying network has significant effects on knowledge spillover.

In this paper, we will study a form of the Schumpeterian growth model (see Refs. [1,2]) on spillover networks discussed in detail later, to investigate how the network structure affects R&D activities and economic growth. As we will see later, in

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http://dx.doi.org/10.1016/j.physa.2016.04.005

reality, a significant feature of networks is heterogeneity: a heterogeneous network has heterogeneous degree distribution. We compare a regular network model with a scale-free network model because a regular network is a representative homogeneous network, and a scale-free network is a representative heterogeneous network and is ubiquitous in reality. In the following analysis, we show what holds in the form of Schumpeterian growth model. Firms are more likely to undertake R&D in scale-free networks. The economic growth rate increases with the increasing heterogeneity of the networks. As the network heterogeneity increases, firms on the network are more likely to undertake R&D, which in turn, increases the growth rate.

1.1. Outline

The rest of the paper is organized as follows. The network externality of R&D is introduced into a form of the Schumpeterian growth model in Section 1.3. The model is extended to a model of networks. The conditions under which a firm undertakes R&D are discussed in Section 2 in terms of the threshold degree of the network beyond which a firm begins R&D. This notion of threshold degree will be discussed in detail in the same section. In Section 3, we study the growth rates of firms in regular, scale-free, and heterogeneous networks and examine how network heterogeneity increases the growth rate. We compare the model on three representative networks: regular network, random network, and scale-free network. In Section 4, we study the threshold degree for a heterogeneous network. Finally, in Section 5 we present intuitive explanations as to why network heterogeneity stimulates investment and accelerates economic growth.

1.2. Schumpeterian growth model

Before we proceed to our model, let us briefly explain a form of the Schumpeterian growth model (see Ref. [1] in detail). For this study we add the network externality of knowledge spillover to the model in Section 1.3. We suppose that only one firm produces the final goods and the consumers consume the final goods. The firm produces the final goods from numerous intermediate goods as inputs. They are indexed by i as we will see later. The final good output Y_t at time t is produced according to the production function

$$Y_t = L^{1-\alpha}\int_0^1 A_{it}^{1-\alpha}x_{it}^{\alpha}\mathrm{d}i, \tag{1}$$

where x_{it} is the ith intermediate good input where $i \in [0, 1]$ at time t, A_{it} is the productivity parameter at time t indexed by i, L is the labor input, and the exponent α satisfies $\alpha \in (0, 1)$. We hereafter use the normalization that $L = 1$ meaning that the labor input is normalized to one and the price of final good is unity. The final good is produced under perfect competition. This means the firm producing the final goods cannot decide the price; the price is determined by supply and demand. Hence, the price p_{it} of the ith intermediate goods at time t is given by $\alpha A_{it}^{1-\alpha}x_{it}^{\alpha-1}$. Each intermediate good is produced by only one firm, which is on one vertex on the network. The ith intermediate good is produced from one unit of final good, and the firm producing ith intermediate good can determine the price p_{it} of the intermediate good, which implies imperfect competition. Therefore, the profit of the ith firm producing the intermediate good-i is given by

$$\Pi_{it} = p_{it}x_{it} - x_{it}. \tag{2}$$

By maximizing the profit Π_{it} of the firm producing i-intermediate goods, we have $x_{it} = \alpha^{\frac{2}{1-\alpha}}A_{it}$. The profit of the firm producing ith intermediate good is given by

$$\Pi_{it} = \pi A_{it}, \tag{3}$$

where π is defined as

$$\pi \equiv (1-\alpha)\alpha^{\frac{1+\alpha}{1-\alpha}}. \tag{4}$$

The firm producing the ith intermediate good either undertakes R&D or does not. If the firm undertakes R&D, in the next period, R&D succeeds with probability μ, and the productivity parameter A_{it} grows to $(1+g)A_{it}$ or fails with probability $1-\mu$. Then, the productivity parameter remains the same. The A can be interpreted as knowledge; it denotes the total factor productivity (TFP) in economics literature (see Ref. [1]). The cost for the R&D investment is a function of the probability μ, productivity A_{it}, and the growth rate g. The R&D cost R_{it} is given by $R_{it} = A_{it}(1+g)n_0(\mu)$, where $n_0(\mu)$ is productivity adjusted R&D cost. This means that as productivity parameter A_{it} increases, R&D costs with the same success probability μ also increase. Let us assume that

$$n_0(\mu) = \eta\mu + \frac{1}{2}\phi\mu^2, \tag{5}$$

where η and ϕ are positive.

The firms are risk neutral. This means that the firms care about the expectation value of the profit only and not about the risk. The expected profit when the firm undertakes R&D at the success probability μ is given by

$$\mu\Pi_{it} - R_{it} = A_{it}(1+g)[\mu\pi - n_0(\mu)]. \tag{6}$$