Effect of Policy and Entrepreneurship on Innovation and Growth: An Agent-based Simulation Approach

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Abstract

Using a model developed by Nelson & Winter (1982) and Zhang (2003) on evolution economics and agent-based simulation (ABS), this paper examines the effect of several factors on high-tech industrial development. Specifically, we focus on the behavior of firms measured by the percentage of R&D resources devoted to innovation or imitation, namely R&D tendency. We show that the variable R&D tendency has a significant effect on the speed of technological level growth. We come to some conclusions as follows: 1) the initial level of technology plays an essential role in the development of new-tech startups; 2) there is an optimal percentage of innovative R&D investment; 3) institutional arrangements will affect the impact of private R&D policy; 4) a good pattern of regional knowledge management is to speed technology diffusion but not keeping technology secret.

JEL Classification: O11, O33, P40, C63
Keywords: Agent-based Simulation, Technology Progress, Industrial Policy

1. Introduction

Because of the complexity of the social system, abstraction often plays an important role in social studies. However, when faced with practical problems, decision makers of government or enterprises always want to know the real effect of their policy in the future, rather than a theoretical result. Benefiting from an increase in computation ability in recent years, agent-based modeling (ABM) and other computation methods, which serve as powerful tools, are becoming a more popular path of social study gradually. (Lempert, 2002)

In this area, more and more literature has emerged. Meyer et al. (2003) proposed a simulation framework to analyze a system with heterogeneous agents using ABM. They also came up with a basic generic algorithm in XML language. Klos & Nooteboom (2001) explored the use of ABM to simulate the profit maximizing behavior of two agent groups, when they bargain with each other, to solve some issues in the economics of transaction cost. Similarly, Carpenter (2002) compared two methodologies, ABM and the traditional method, in understanding the nature of bargaining. He found that ABM performed well in selecting equilibria in most situations.

Development of high-tech industry is one of the hottest topics in economics, considering its power to stimulate world economic development. How to succeed in technology innova-

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tion, how to achieve the rapid growth of industry, how to choose the best behavior, many questions have to be answered. Learning from historical experience, we know that personal startups have to be treated as a crucial force in high-tech industry. The case of Silicon Valley shows us the astonishing vigor of startups. Meanwhile, the demise of the 128-route area at the end of the last century also gave us a case in point of the shortage of big enterprises in high-tech industry (Saxenian, 1996).

From the perspective of government, the focus should be on macro-level growth. Particularly, the developing countries have to face a different situation to develop its high-tech industry. As revealed by Forbes and Wield (2002), self-reliance is not always the correct way for the followers to catch up to the leaders. On the contrary, copying and buying technology can save the capital and human resource in a more efficient way.

Despite the heterogeneous nature of agents, the total contribution of every individual startup constitutes the high-tech industry performance of an area. As we have noted, this is just the advantage of ABM. Zhang (2003) employed ABM to show the dynamics of high-tech industry clusters. Similarly, Marz et al. (2006) also use this model to summarize the characteristics of industry clusters. However, these studies stopped on the surface of the phenomenon and historical experience, instead of researching the optimized growth path.

In our research, we set up a market made up of agents with technology. By applying the ABM method, the best behavior option is found under different institutional environments. From the disorder of individual behavior, statistical conclusions can be drawn to compare the effect of policy on the function of the group as a whole.

2. Model

The model used in our study is transformed from the work of Zhang (2003) and Marz et al. (2006). Actually, both works can be traced back to. An evolutionary theory of economic change, one of the milestones of evolutionary economics, which was written by Nelson and Winter in 1982. According to their book, R&D activities are divided into two different kinds, one is innovation, and the other is imitation. To some extent, the sharing of investment between innovation and imitation can be regarded as the R&D behavior of the agent. Therefore, we define the R&D tendency m as the percentage of investment on innovation from the total R&D expenditure. Considering the long term of the R&D process, the tendency is treated as a stable variable during the simulation. Of course, it is questionable to treat the tendency of R&D as an unchanged variable. In the real world, the firm behavior will change according to its R&D course. If it succeeds in the new product invention, it will decrease the investment on R&D, vice versa. However, to observe the result of a strategy, it is reasonable to assume the proportion on innovation and imitation maintain stable. Besides, although its behavior may change at times, startup firms often have the distinct characteristics of their owner, innovative or imitative.

In the model analyzed here, we set up 150 groups of agents, with 100 agents in each group. Every agent learns from the others in its group, affects the others, and also is affected by the others. The connection between different groups is achieved on the market. There is a significant difference between our model and the model of Zhang (2003) and Marz et al. (2006) in the network of agent connection function. In their models, the agents were put on a grid
network, which means an agent can only be affected by his neighborhood. This change makes the model more close to the real world in that people like to cluster with people of similar background or in the same neighborhood.

The model consists of 3 parts, which are the behavior of the market, the production behavior of agents, and R&D behavior of agents. Moreover, the agent will be affected by others to determine whether to start up a company of his own. The probability of entrepreneurship of agent \( j \) in group \( i \) at time \( t \) is

\[
P_{i,j,t} = \frac{1}{500} \sum_{k=1}^{100} \frac{K_{i,k,t-1}}{a_{i,k,t-1}} + p_0,
\]

where \( K_{i,k,t-1} \) and \( a_{i,k,t-1} \) present the capital scale and age of agent \( k \) in group \( i \) at time \( t-1 \) respectively. Here, we employ the same thinking in Zhang (2003), which means that the more rapid and successful start-up will give more stimulation to others. So, we assume that the effect of others’ performance consists of two parts, the aggregate capital scale and the time he made his startup.

**Market**

The price of production is defined as

\[
P_t = \frac{D_t}{S_t}
\]

\( D_t \): Market demand at time \( t \);

\( S_t \): Market supply at time \( t \), which equals to the total production of all company,

\[
S_t = \sum_i Y_{i,t}
\]

**Production**

The production of a company (agent who has set up a firm) is defined as a Cobb–Douglas function as follows:

\[
Y_t = h_t K_t^a \quad (a < 1)
\]

\( h_t \): Technology of a company at time \( t \);

\( K_t \): Accumulative capital at time \( t \).

The profit of the company after sales is

\[
\pi_t = P_t Y_t - c Y_t,
\]

where \( c \) presents the resource cost of product per unit. Here, the cost includes not only the resource used in production process, also the advertisement and promotion cost. Therefore, it will decrease as the technology increases. However, the profit is still increasing as the technology of the firm increases.

**R&D activities**

When a firm earns a profit during sales, it will invest a proportion of profit into R&D activities to enhance its technology, split into one part for innovation, another part for imitation. The remainder will be used to expand the capital stock.
When $\pi_i > 0$,

$$IN_{i+1} = IN_i + m \cdot n \cdot \pi_i, \quad (6)$$

$$IM_{i+1} = IM_i + (1-m) \cdot n \cdot \pi_i, \quad (7)$$

$$K_{i+1} = K_i (1-d) + (1-n) \cdot \pi_i; \quad (8)$$

When $\pi_i \leq 0$,

$$K_{i+1} = K_i (1-d) + \pi_i, \quad (9)$$

where $IN$ and $IM$ presents the investment on innovation and imitation respectively. The variables $m$ and $n$ show the percentage of innovation to total R&D investment, the percentage of R&D to total profit, respectively. Coefficient $d$ is the depreciation rate.

When R&D investment touches a threshold, the firm can perform a technology evolution. When $IN_{i,j,t} \geq f(K_{i,j,t})$, the firm will succeed in innovation, the new technology $h'_{i,j}$ will be

$$h'_{i,j} = \left( \frac{h_{i,j,t}}{h_{i,t-1}} \right) \left( \frac{h_{i,t}}{h_{i,t-1}} \right) h_{i,t} + \varepsilon. \quad (10)$$

Here, we assume that the innovation result depends on the technology growth rate both the firm itself and the whole society, and the company's current technology. Besides, the success of the innovation will also be affected by some random factors, i.e. the variable $\varepsilon$($\varepsilon \sim U(-0.1,0.1)$). That means the new technology is possible lower than the current one. Therefore, the firm will choose the higher one used in its production next term.

$$h_{i,j,t+1} = \max(h_{i,j,t}, h'_{i,j}), \quad (11)$$

And then, the accumulated innovation investment should be

$$IN_{i,j,t+1} = IN_{i,j,t} - f(K_{i,j,t}), \quad (12)$$

Similarly, when $IM_{i,j,t} \geq g(K_{i,j,t})$, the firm can implement a technology imitation. Agent $i$ will capture the highest technology in his group:

$$h_{i,j,t+1} = \max(h_{i,j,t}, h'_{i,t}(\text{max})), \quad (13)$$

And the accumulated imitation investment should be

$$IM_{i,j,t+1} = IM_{i,j,t} - g(K_{i,j,t}), \quad (14)$$

Here, we define $f(K) = \beta K^3$, $g(K) = \gamma K^3$ as the threshold of technology progress.

### 3. Development of different types of groups

To consider the effect of R&D policy on the development of companies, we define 3 different kinds of R&D policy according to the possible values of the R&D coefficient $m$, which are imitative ($0.1 < m < 0.3$), neutral ($0.4 < m < 0.6$), and innovative ($0.7 < m < 0.9$), respectively. Here, $m$ is a random variable which obeys uniform distribution of its region. In the simulation, we define every kind of strategy holders covers one third of the 150 groups, and all the agents in the same group implement an identical strategy $m$. The periods of the simulation are set to 500, and the initial capital and technology of agent is uniformly random between 0 and 1.
3.1 Technology development

Concerning the high-tech industry, the level of technology plays a key role, which determines the status of a company, an area, and even a country, in the market competition. Therefore, we want to scrutinize the factor that will affect the technology progress and to what extent they will determine this process. As we simplified the complicated internal operational mechanism of company, the factor mainly lie among its initial character, such as initial technology level, initial capital, and also the R&D tendency.

Results of regressions of technology growth are shown at Table 1. We can see that initial capital has little relationship with tech-growth, no matter the type of R&D policy. However, the coefficient 0.1 is close to being significant for the innovative groups. This suggests greater need for financial support of innovative R&D activity. On the other hand, if firms can imitate others with lower cost, the time for catching up with the leaders will be shortened.

<table>
<thead>
<tr>
<th></th>
<th>Imitative</th>
<th>Neutral</th>
<th>Innovative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Capital</td>
<td>−0.04</td>
<td>−0.01</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>(−0.808)</td>
<td>(−0.067)</td>
<td>(1.552)</td>
</tr>
<tr>
<td>Initial Technology</td>
<td>1.20**</td>
<td>−0.07</td>
<td>2.08**</td>
</tr>
<tr>
<td></td>
<td>(4.437)</td>
<td>(−0.195)</td>
<td>(7.517)</td>
</tr>
<tr>
<td>R&amp;D Tendency</td>
<td>0.92</td>
<td>0.87*</td>
<td>−0.66*</td>
</tr>
<tr>
<td></td>
<td>(0.756)</td>
<td>(1.923)</td>
<td>(−2.552)</td>
</tr>
<tr>
<td>Observations</td>
<td>33</td>
<td>34</td>
<td>27</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.9844</td>
<td>0.9730</td>
<td>0.9882</td>
</tr>
<tr>
<td>Adj. R-Square</td>
<td>0.9500</td>
<td>0.9390</td>
<td>0.9455</td>
</tr>
</tbody>
</table>

Note: *Significant at 0.1, **Significant at 0.01, t statistics in parentheses

Compared to initial capital, initial technology makes a greater contribution to the technology growth. For groups with a clear R&D policy (innovative or imitative), the positive relationship between initial technology and final technology level is significant at the 1% level. Meanwhile, neutral R&D policy will result in growth depending more on the R&D tendency: the more investment on innovation, the higher tech growth it will achieve. However, this is not true when we turn to the innovative groups (significant at the 10% level). The result reveals that the investment on innovation has negative effect on technology development among innovative groups, proving the importance of learning from others.

3.2 Capital scale development

The other index measuring the prosperity of an industry is the capital scale. From the regression results listed in Table 2, we find that the initial conditions only affect the capital growth of innovative groups. As expected, initial technology and capital stock have a positive effect on capital stock growth, and initial technology has nearly 6 times the effect of initial capital. However, once again, more investment on innovation is found blocking the capital growth.
4. Simulation of the influence of the intellectual assets protection system

The growth of high-tech industry depends on whether the institutional arrangement can stimulate the potential of the human resource, other than the money paid by government, or the persons appointed by managers (Wu, 2002). There are many aspects when we talk about the institutions. However, as far as high-tech industry is concerned, the intellectual assets protection system is one of the most important parts. On the one hand, this system will encourage people to invent new product by giving them a monopolistic profit; on the other hand, strict protection will prevent people from learning from others’ experience at low cost, which block the spillovers across areas.

To illustrate the effect of the protection system, our study simulated three kinds of intensity of protection to examine the performance of groups under different environments. We defined the growth rate of technology as

$$r = \left( \frac{h_t}{h_0} \right)^{\frac{1}{t}} - 1, \quad (15)$$

where $t$ presents the average life of the firms in a group, $h_t$ is the final level of technology, and $h_0$ is the initial level of technology. We assume this rate is decided as follows:

$$r = a_1 h_0 + a_2 h_0 + a_3 t + a_4 m + a_5 m^2. \quad (16)$$

From the analysis in section 3, innovative R&D may have negative effect when it exceeds some threshold, which suggests an optimal percentage of innovation exists. Therefore, we assume that $a_4 > 0$, $a_5 < 0$, and the best sharing of innovation to total R&D investment is $-\frac{a_4}{2a_5}$, achieving the largest growth rate of technology. And the regression result proved our supposition.

From the results in table 3, we can see that technology growth rate is affected by the level of initial technology rather than by the initial capital stock. With the increasing of the protection intensity, the reliability of growth rate on initial technology is decreasing; meanwhile the effect of the R&D policy is increasing. This phenomenon suggests that
Table 3. Regression of technology growth rate under three different intellectual asset protection regimes

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>Standardized Coefficient</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Initial Capital</td>
<td>0.0000</td>
<td>0.0132</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>(0.201)</td>
<td>(0.689)</td>
<td>(13.638)</td>
</tr>
<tr>
<td>Initial Technology</td>
<td>1.0542**</td>
<td>0.9366</td>
<td>0.7515**</td>
</tr>
<tr>
<td></td>
<td>(24.253)</td>
<td>(13.638)</td>
<td>(8.899)</td>
</tr>
<tr>
<td>Firm Life</td>
<td>−0.0000</td>
<td>−0.0115</td>
<td>0.0002**</td>
</tr>
<tr>
<td></td>
<td>(−0.284)</td>
<td>(2.703)</td>
<td>(1.600)</td>
</tr>
<tr>
<td>R&amp;D Tendency</td>
<td>0.1240*</td>
<td>0.1908</td>
<td>0.3307**</td>
</tr>
<tr>
<td>Square of R&amp;D Tendency</td>
<td>−0.1212*</td>
<td>−0.1445</td>
<td>−0.2978**</td>
</tr>
<tr>
<td></td>
<td>(−2.102)</td>
<td>(−3.791)</td>
<td>(−3.791)</td>
</tr>
<tr>
<td>Observation</td>
<td>90</td>
<td>86</td>
<td>76</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.9879</td>
<td>0.9790</td>
<td>0.9738</td>
</tr>
<tr>
<td>Adj. R-Square</td>
<td>0.9872</td>
<td>0.9777</td>
<td>0.9720</td>
</tr>
<tr>
<td>Optimum R&amp;D Tendency</td>
<td>0.5115</td>
<td>0.5553</td>
<td>0.6257</td>
</tr>
</tbody>
</table>

Note: *Significant at 0.1, **Significant at 0.01, t statistics in parentheses

strengthening the protection of intellectual assets will inspire the sparkle of innovation, and make agents break away from restrictions due to initial conditions.

5. Conclusion

The paper carried out an agent-based simulation to find out the effect of R&D policy on the development of high-tech startups. In order to clarify our intent, the agent is divided into 3 kinds, imitative, neutral and innovative. Moreover, we considered the intellectual assets protection system as an institutional factor to examine the reaction of firms to different environments. Here, we come to conclusions as follows:

1. the initial level of technology plays an essential role in the development of high-tech startups, no matter the growth of technology or the capital scale;
2. investment in innovation is not necessarily good for growth of industry, and there is an optimal percentage of innovative R&D investment;
3. institutional arrangements will affect the impact of private R&D policy, as the intensity of intellectual assets is increased, the optimal share of R&D expenditure out of profit will also increase.

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