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DYNAMIC ANALYSIS OF COMPETITIVE TECHNOLOGY INNOVATION DIFFUSION MODEL

Ming-Chang Lee[1]
[1]*National Kaohsiung University of Applied Sciences, Taiwan*

ABSTRACT
Technological innovation diffusion theory and models play an important position in the forecasting field. Many researchers use these models to predict in different areas. Although the basic Bass model easy to use, but there are many limitations, the effects of Bass diffusion model for innovation diffusion factors (such as price, advertising, income, and technology supply) cannot measure. In order to find the principles of the relationships between innovations and the importance of the affection on the active of an innovation, this paper reviews the application of innovation diffusion models in the field of demand forecasting, through summarizing and analyzing a variety of predication models. Competitive innovation diffusion model include of monopolistic competition in a technology diffusion models and the evolution of the coexistence of two technologies competing diffusion evolution model. Under the aim of this paper, it uses mathematical methods in-depth analysis of competition, technological innovation diffusion models. This mathematical method includes nonlinear equilibrium point, stability analysis. Through the asymmetric evolutionary stability analysis, the paper derived the long-term evolutionary stable equilibrium of the innovation. Finally, the paper gives some suggestions on how to strength the competitive technology innovation in diffusion model.

Keywords: Technological innovation diffusion theory, Bass model, Stability analysis, Evolutionary stable equilibrium, Monopoly diffusion model, Nonlinear equilibrium point.

Contribution/ Originality

The paper's primary contribution is the establishment of a competitive technological innovation diffusion model base on Bass model. It has built monopoly competitive diffusion model, the coexistence of two technologies competing diffusion model and lemma and theorem to solve this nonlinear equilibrium point.

1. INTRODUCTION

Technical innovation is an essential driver of productivity growth and improves people's living standards. Innovation solved science, technology and economic dislocation and to promote technological progress methodology. Traditional forecasting methods are mainly applied in time

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series trend method, based on existing data to predict the market value; it does not consider environmental factors. Therefore, the expected result is not enough convincing. The technology innovation diffusion theory and models emergence to bring a new direction in forecast demand.

Technological innovation diffusion model is a component of technological innovation diffusion theory. It uses mathematical methods to analyze the process of technological innovation diffusion. It uses a qualitative analysis of innovation diffusion deepening and development. Under the aim of this paper, theoretical relationships are enriched by the conclusions drawn from literature review. It includes technological innovation diffusion models (such as Bass diffusion model). By studying conceptual studies, this paper uses mathematical methods in-depth analysis of competition, technological innovation diffusion models. These findings provide high-tech industry developing marketing strategy.

2. RELATED WORK

2.1. Bass Diffusion Mode

Bass diffusion model is the basic S-type model. In Bass model, it assumes that throughout the product life cycle, there will have N times for the first purchase product, and the number of each purchase is one unit (Bass, 1969). The market is divided into two parts: the potential market and the current market. The mainly affected are two mechanisms in users' potential market transform into the current market. First affect is the mass media (such as advertising). P is innovation coefficient, it indicates the size of the degree of influence; the second affect is crowd's verbal communication. q is imitation coefficient, it indicates the size of the degree of influence.

Bass diffusion mode：

$$\frac{dN(t)}{d(t)} = p[N - N(t)] + \frac{q}{N} N(t)[N - N(t)] \qquad (1)$$

Where

N : The total number of potential uses of the product

$N(t)$: The cumulative total number of uses of the product at time of t

$\frac{dN(t)}{dt}$: The number of uses of the product at the time of t

$p[N - N(t)]$: The number of buyers is only affected by external factors, it have no affected by purchased the product's buyers. It is called "innovation adopters".

$\frac{q}{N} N(t)[N - N(t)]$: The number of buyers is affected by the previous buyers for purchasing this product. It is called "imitators".

Solving (1) yields

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$$N(t)=N(\frac{1-e^{-(p+q)t}}{1+\frac{q}{p}e^{-(p+q)t}})$$

Calculate $\frac{dN(t)}{dt}$ and the maximum value of $\frac{dN(t)}{dt}$ at time t^*.

$$\frac{dN(t)}{dt}=N(\frac{p(p+q)^2e^{-(p+q)t}}{[p+qe^{-(p+q)t}]^2})$$

$$t^*=\frac{1}{p+q}\ln(\frac{p}{q}) \qquad (2)$$

$$N(t^*)=N(\frac{1}{2}-\frac{p}{2q})$$

$$\frac{dN(t^*)}{dt}=N\frac{(p+q)^2}{4q}$$

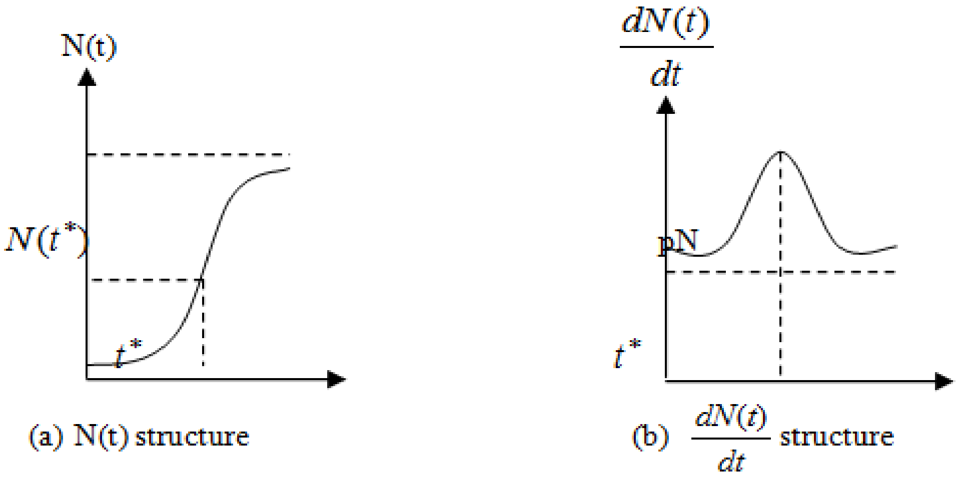

Figure-1. Bass Model Structure

Figure 1 denoted as Bass Model Structure. Basic Bass diffusion model is easy to understand and easy to use. For example, using the Bass diffusion model as forecast conditioner, color TV buyers. However, there are many limitations, affecting the accuracy of the predictions for the limitation. Scholars have proposed various expansion models to supplement the basic Bass diffusion model.

2.2. Diffusion Model's Demand Forecast

The sales model for forecasting TV made by Bass in 1969 has paved the way foe the following researches on innovation diffusion. After that, there are also many improved models. Many scholars use Bass diffusion model to study the product market problems, such as bimodal

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model Steffens (Steffens, 2003) Creative and imitator s model (Tanny and Derzko, 1988). Steffens and Murphy (1992) adoption multi-group diffusion model, the price factor adds into Bass S model, which establishes a dynamic pricing model. Bottomley and Fildes (1998) consider electronic product, use price factor into Bass S model. Horsky and Simon (1983) use advertising factor adds into Bass S model, it added advertising in the study of American telephone banking as an explanatory variable, verify the possibility affect of using advertising to this model. Simon and Sebastian (1987) think that the advertising works only imitators, and thus the established model is called imitation model. Mahajan and Peterson (1978) assume that N is the market potential variable. Kalish (1985) assume that market changed over time. Centrone *et al.* (2007) consider a continuous function in process-specific market and process of demographic death. It constructs of the binomial innovation diffusion model of economic and demographic situation and uses this model to predict for mobile phone. Dodson and Muller (1978) join a rebury factor in the purchase mode. Chanda and Bardhan (2008) distinguish between first-time buyers and repeat buyers in their studies, and the market environment will also be considered separately. Some manufacturers often generations while operating, and thus to be a more realistic case. Therefore, in this model they consider update alternative technical problems such (Norton and Bass, 1987) has some shortcomings, such as the model assumes that the innovation factor, imitation coefficient and market potential do not change throughout the innovation process. In the study of phone diffusion model, Islam and Meade (1997) find that the innovation factor tends to increase rather than constant. But these models can't show the dynamic relations of competition and influence between each other. Krishnan *et al.* (2000) pointed out that a technical innovation into the market, there is often a corresponding product and competition, and they used two Bass models (competitor 1 and competitor 2) to establish a competitive new product diffusion model.

3. ESTABLISH A COMPETITIVE INNOVATION DIFFUSION MODEL

In this paper, a new dynamic model on two-innovation diffusion in the same time to explore the innovation interrelationship and the influence on the potential adopters who have planned to adopt other innovation is not taken into account in former competition models.

Competing technology innovation diffusion process, not only depends on the characteristics and related factors of the technology itself, but also on the competitive characteristics of the technology. In competing technology innovation diffusion, it need establish their simultaneous diffusion process differential equation. During the diffusion of innovation, new companies or customers adopt it and become its adopters. However, for the influence of the existence of other innovations, which planned to adopt this innovation, will speed up or slow down their step, even turn back to adopt other innovation. Assume that a single technology diffusion models for Bass model. In two technologies significantly different, competing technology innovation diffusion tend to technical domination of the market. For example, in technology monopoly diffusion model, technologies A are better than the technologies B in technology properties. Technologies

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B cannot be occupied technologies a market diffusion. In two technologies competing diffusion evolution model, if techniques a comparative with techniques B, its advantage is not obvious. Technologies A cannot be occupied market diffusion. In addition, if the function of A's technologies more powerful technology, but its production cost is very high, prices are high, B diffusion technologies possible to suppress A's diffusion technologies (such as price). If technology A forced entry market, A's market diffusion is also difficult to make penetration to B's market diffusion.

4. MODEL ANALYSIS

4.1. Competitive Technology Monopoly Diffusion Model

4.1.1. Establish Monopoly Diffusion Model

N : The total number of potential uses of the product

$N_1(t)$: The cumulative total number of uses of the product at time of t in technology A

$N_2(t)$: The cumulative total number of uses of the product at time of t in technology B

α : The coefficient of diffusion

β : The coefficient of diffusion is due to technical A's technology advantages B's technology technical A

γ : The coefficient of diffusion

When the two technologies compete in the same market, technology diffusion A consists of two parts: First, the use of technology has not yet spread to the user B, the diffusion speed (rate) was $\alpha(N-N_1(t)-N_2(t))N_1(t)/N$. Second, the technology diffusion B occupied market, the diffusion speed (rate) was $\beta N_1(t)N_2(t)$. Similarly technology diffusion B also consists of two parts: First, the market loss caused by technologies diffusion A. It called a negative spread, the diffusion speed (rate) was $-\beta N_1(t)N_2(t)$. Second it is not yet spread to the user's market. The diffusion speed (rate) was $\gamma(N-N_1(t)-N_2(t))N_2(t)/N$. Since $\gamma>0$, it knows that $\alpha>\beta N$.

Then the diffusion equation of innovation gives by (Differential model):

$$\frac{dN_1(t)}{dt}=\alpha(N-N_1(t)-N_2(t))N_1(t)/N+\beta N_1(t)N_2(t) \qquad (3)$$

$$\frac{dN_2(t)}{dt}=\gamma(N-N_1(t)-N_2(t))N_2(t)/N-\beta N_1(t)N_2(t)$$

After finishing

$$\frac{dN_1(t)}{dt}=\alpha(1-\frac{N_1(t)}{N}-(\frac{1}{N}-\frac{\beta}{\alpha})N_2(t))N_1(t) \qquad (4)$$

$$\frac{dN_2(t)}{dt}=\gamma(1-\frac{N_2(t)}{N}-(\frac{1}{N}-\frac{\beta}{\gamma})N_1(t))N_2(t)$$

4.1.2. Nonlinear Equilibrium Point

Definition 1 A point p_1 (x_1,y_1) is called a nonlinear equilibrium point of (5) if $f(x_1,y_1)=g(x_1,y_1)=0$.

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Nonlinear system

$$\frac{dx}{dt} = f(x, y) \qquad (5)$$

$$\frac{dy}{dt} = g(x, y)$$

Lemma 1. Assume λ_1 and λ_2 are the roots of technology innovation diffusion equilibrium point characteristic equation (differential equation model).

(a) If $\lambda_1 > 0$, $\lambda_2 > 0$ then equilibrium point is unstable.

(b) If $\lambda_1 < 0$, $\lambda_2 < 0$ then equilibrium point is stable.

(c) If $\lambda_1 > 0$, $\lambda_2 < 0$ then equilibrium point is saddle point

It considers the system (6).

$$\alpha(1 - \frac{N_1(t)}{N} - (\frac{1}{N} - \frac{\beta}{\alpha})N_2(t))N_1(t) = 0 \qquad (6)$$

$$\gamma(1 - \frac{N_2(t)}{N} - (\frac{1}{N} + \frac{\beta}{\gamma})N_1(t))N_2(t) = 0$$

The Eq. (6) has three equilibrium points. O (0, 0), P_2 (N, 0), P_4 (0, N). Equilibrium equation divided the first quadrant into three regions: ÄOP_1P_4, quadrilateral $P_1P_2P_3P_4$ and the rest of unlimited area.

Theorem 1 Let $\alpha > \beta$ N

(1) O (0, 0), p_2 (N, 0), p_4 (0, N), the system of three equilibrium points, which are unstable nodes, stable nodes, saddle points.

(2) For every start point $(N_1(t), N_2(t))$, when $t \to \infty$, $N_1(t) \to N, N_2(t) \to 0$

Proof : (1) Equation (6) have three equilibrium points, which are (0, 0), (N, 0) ,(0, N) respectively.

First it will show point (0, 0) is an unstable node. Since the characteristic equation is $(\lambda - \alpha)(\lambda - \lambda) = 0$ that is $\lambda_1 = \alpha > 0$, $\lambda_2 = \gamma > 0$, then (0, 0) is unstable node from lemma 1. ◦

Similarly point (N, 0) is a stable point. Since the characteristic equation is $(\lambda + \alpha)(\lambda + \beta N) = 0$ that is $\lambda_1 = -\alpha < 0, \lambda_2 = -\beta N < 0$, then (N, 0) is stable node.

Similarly point (0, N) is a saddle point. Since the characteristic equation $(\lambda + \lambda)(\lambda - \beta N) = 0$, that is $\lambda_1 = -\lambda < 0, \lambda_2 = \beta N > 0$, then (0, N) is a saddle point. This completes the proof.

(2) In equation (6), Line $1 - \frac{N_1(t)}{N} - (\frac{1}{N} - \frac{\beta}{\alpha})N_2(t) = 0$ and line $1 - \frac{N_2(t)}{N} - (\frac{1}{N} + \frac{\beta}{\gamma})N_1(t) = 0$ divided the first quadrant into three regions: ÄOP_1P_4, quadrilateral $P_1P_2P_3P_4$ and the rest of unlimited area.

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In ÄOP$_1$P$_4$, it has $\frac{N_1(t)}{dt} > 0$, $\frac{N_2(t)}{dt} > 0$, quadrilateral P$_1$P$_2$P$_3$P$_4$ it has $\frac{N_1(t)}{dt} > 0$, $\frac{N_2(t)}{dt} < 0$ and the rest of unlimited area, it has $\frac{N_1(t)}{dt} < 0$, $\frac{N_2(t)}{dt} < 0$. This show that for every start point $(N_1(t), N_2(t))$, when t ∞, $N_1(t) \to N, N_2(t) \to 0$. Just as shown in Fig. 2, system (6) tends to point (N, 0). This means that in monopoly diffusion model, technology diffusion A has occupied its maximum potential market.

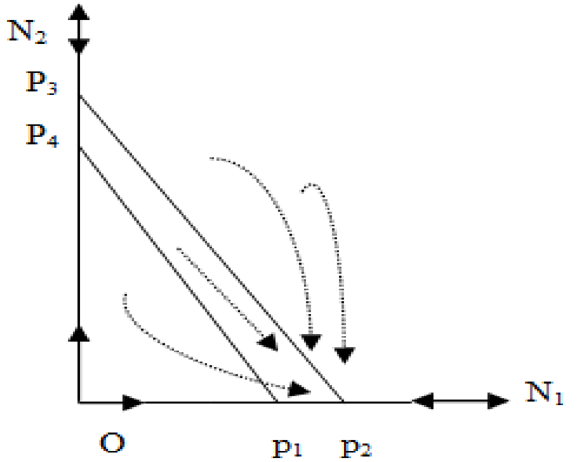

Figure-2. Monopoly competitive diffusion process schema

4.2. The Coexistence of the Two Technologies Competing Diffusion Model

Assume $\beta = 0$ in equation (6), the result denoted as (7). Equation (7) present the technology A has occupied the market. The technology B cannot spread to the technical A's market.

$$\frac{dN_1(t)}{dt} = \alpha(1 - \frac{N_1(t)}{N} - \frac{N_2(t)}{N})N_1(t) \qquad (7)$$

$$\frac{dN_2(t)}{dt} = \gamma(1 - \frac{N_2(t)}{N} - \frac{N_1(t)}{N})N_2(t)$$

The equilibrium points located in the line $1 - \frac{N_1(t)}{N} - \frac{N_2(t)}{N} = 0$. This line divided the first quadrant into two regions: ÄOP$_1$P$_2$, and the rest of unlimited area. In ÄOP$_1$P$_2$, it has $\frac{N_1(t)}{dt} > 0$, $\frac{N_2(t)}{dt} > 0$, the rest of unlimited area, it has $\frac{N_1(t)}{dt} < 0$, $\frac{N_2(t)}{dt} < 0$. Assume Q is the starting point for the system (see Fig. 3), Q in the area Ä OP$_1$P$_2$, then $\frac{N_1(t)}{dt} > 0$, $\frac{N_2(t)}{dt} > 0$. The system market diffusion track is falling on shaded QAB, the equilibrium points of the system falls on the line segment $\overline{AB}$.

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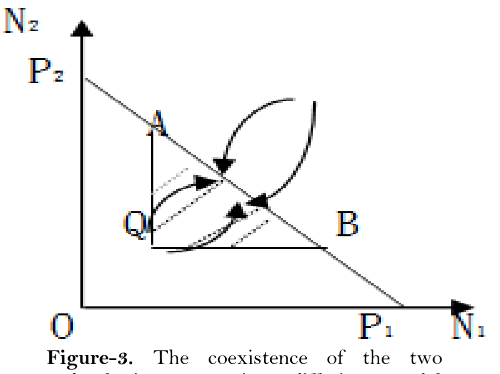

Figure-3. The coexistence of the two technologies competing diffusion model process schema

From Fig. 3, two techniques eventually co-exist in the market, and each occupies different user to stabilize the market. The number of market users depends on the initial size and the rate of diffusion of the two technologies. If the technology A enters into market, the technology B has occupied most of the market. Technology A cannot penetrate the market and will be out of the market. If the technology B just in promotion in market, then this time technology A and B can co-exist in the market.

4.3. The Coexistence of the Two Technologies Competing Diffusion Model Developed in Different Market

Technology A enters into the technology B market but technology A is no obvious advantage than technology B. Technology B and technology A coexist with r the same market. Two technologies cannot meet the current situation, they will use a variety of means (such as advertising, etc.), and give full play own advantage, to strive for greater market users. The technology a diffusion speed (rate) was $\alpha(N - N_1(t) - \sigma N_2(t))N_1(t)/N$.

The technology B diffusion speed (rate) was $\gamma(N - N_1(t) - \omega N_1(t))N_2(t)/N$. Where $\sigma N_2(t)$ is the number of technology B penetrating to technology A market. $\omega N_1(t)$ is the number of technology A penetrating to the technology B market . Then the diffusion equation of innovation gives by (Differential model):

$$\frac{dN_1(t)}{dt} = \alpha(N - N_1(t) - \sigma N_2(t))N_1(t)/N \qquad (8)$$

$$\frac{dN_2(t)}{dt} = \gamma(N - N_1(t) - \varpi N_1(t))N_2(t)/N$$

After finishing

$$\frac{dN_1(t)}{dt} = \alpha(1 - \frac{N_1(t)}{N} - \frac{\sigma N_2(t)}{N})N_1(t) \qquad (9)$$

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$$\frac{dN_2(t)}{dt} = \gamma(1 - \frac{N_2(t)}{N} - \frac{\omega N_1(t)}{N})N_2(t)$$

(a) If technologies A and B occupy different market, than $\sigma = \omega = 0$.

(b) If technologies A and B compete in the same market, than $\sigma = \omega = 1$. This is Equation (7) model.

(c) If technologies A and B in order to avoid vicious competition in the same market. It developed in a common market, and developed in other different markets, then $0 < \sigma = \omega < 1$

The case of $0 < \sigma = \omega < 1$, Equilibrium equation：

$$\alpha(1 - \frac{N_1(t)}{N} - \frac{\sigma N_2(t)}{N})N_1(t) = 0 \qquad (10)$$

$$\gamma(1 - \frac{N_2(t)}{N} - \frac{\omega N_1(t)}{N})N_2(t) = 0$$

Equation (10) have four equilibrium points, which are O(0,0) ，P_1 (N,0), P_3(N/(1-ω), $N/(1-\sigma)$) ，P_4(0, N)) respectively. Equilibrium equation divided the first quadrant into four regions: quadrilateral $OP_1P_3P_5$, Ä$P_3P_4P_5$ · Ä$P_1P_2P_3$ and the rest of unlimited area (see Fig. 4).

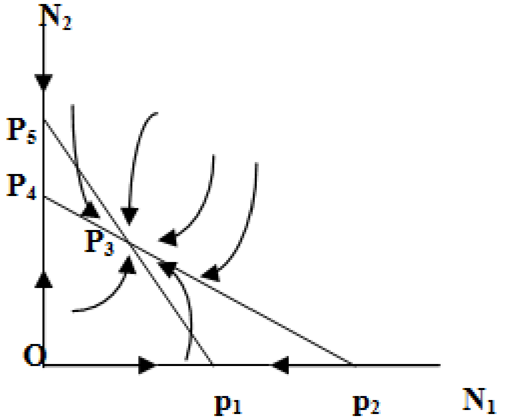

Figure-4. The coexistence of the two technologies competing diffusion model developed in a common market, and developed in other different markets process schema

Theorem 2. Let $0 < \sigma = \varpi < 1$

(1) O(0,0), p_1(N,0), p_4(0,N), P_3(N/(1-ω), $N/(1-\sigma)$), the system of four equilibrium points, which are unstable nodes, saddle points, saddle point, and stable nodes,.

(2) For every start point $(N_1(t), N_2(t))$, when $t \longrightarrow \infty$, $N_1(t) \to \frac{N}{1-\omega}, N_2(t) \to \frac{N}{1-\sigma}$

Proof: Similar Theorem 1

From Fig 4. users of both techniques are increasing, and over time, they eventually reach a steady state.

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5. DISCUSSION AND CONCLUSION

Various models have been constructed to explore the principles of innovation diffusion and make share. Many competition models has been established to show today's competitive social environment in which increased adoptions of one innovation result in decreased adoptions of other innovations. The aim of this paper is the establishment of a competitive technological innovation diffusion model based on Bass model, and the evolution of the coexistence of two technologies competing diffusion evolution model. Under the objectives of this paper, the coexistence of the two technologies competing diffusion model and monopoly competitive diffusion model have been built, and give a lemma and theorem to solve nonlinear equilibrium point. We find that if the market is too fierce, so it will need to find new space for survival and development, it uses the maximum limit and optimal allocation of resources to develop new markets. This paper is focusing on dynamic diffusion model in which innovations are having an effect on others during the process of diffusion. In next phase, it has note take the advertising, price and the economic environment into account, which will be included in further research.

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