지식확산에 관한 실증분석 모델
(TWO MODELS FOR KNOWLEDGE DIFFUSION)

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초 록 기업의 생산성향상과 이익률에 영향을 줄 수 있는 지식이 경제 전반에 확산되어 나가는 과정은 한 나라의 경제발전속도에 영향을 미치는 중요한 요인이다. 기업 측면에서는 도입하려는 기술이 도입 후에 그 기업의 이익을 높여 줄 수 있다면 도입하지 않을 이유가 없다. 하지만 미래 수요의 불확실성이나 기술발전 방향의 불확실성 등으로 해서 기업으로서는 도입 후의 이익을 정확히 사전적으로 측정하기는 어렵다.

본 논문에서는 학계에서 일반적으로 사용되고 있는 두 가지 지식확산 모델을 설명하고자 한다. 그 하나는 하나의 새로운 기술이나 상품이 시간이 흐름에 따라 어떻게 전체 사용 가능자(population)에게 확산되는 지를 보여주는 1) Epidemic Diffusion Model (흔히 S자형 - Sigmoid - 모델이라고도 한다.)과 어떤 도입자가 어느 시점에서 대상이된 새로운 기술을 도입할 것인지 아닌지를 결정하는 모델로서 2) Probit Diffusion Model (프로빗 모델)을 중심으로 한다. 그리고 이러한 지식확산과정과 속도에 영향을 줄 수 있는 기업 내부적 요인으로서 도입하고자 하는 기업의 누적된 경험이 중요하다는 것과 기업 외부적 요인으로서 네트웍 효과와 같은 요인들을 설명하였다.

New knowledge is useful only after it is applied to the actual production activity, and it is the entrepreneur's role to adopt available technology into the application. The profitability from adopting a new technology is the main determinant in the process of adopting it, and a firm is the basic unit that determines the adoption of new technology. Decision makers in the firms are the acting entrepreneurs. The firm's profitability from adopting innovation depends on several factors, such as market structure, technological expectations in the relevant fields, the speed of technological progress around the adopting innovation, the firm's technological capability, and other externalities. Two kinds of externalities with related spillover effects are emphasized: 'market externality' and 'technological externality'. Market externality is known to be a 'rent-spillover' where the down stream firm gets the transfer from the up-stream firm's rent from a specific innovation,

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whereas technological externality is the spillover of innovative knowledge from other firms and/or other industries.

1) Determinants of Diffusion Process

When new technology is for sale by other research firms, potential users decide if they will adopt it or not. If adopted, they pay the fee for using the patented new technology or pay the actual price of machinery that has been embodied with the specific innovative technology. Many factors affect the adoption decision, such as the current and future development of relating technology, competitor's behavior about the new technology, and so on. These bind the profitability of a firm when adopting new technology. The profitability of new technology is also affected by the market structures of the relevant industries. In this way, the shape of the diffusion curve is also affected by the many strategies of firms in those industries.

The characteristics of innovation are the major determinants for the speed and scope of diffusion. First of all, the appropriability of the would-be adopter is an important factor if he/she adopts the new technology or not. Even if a new product or process technique is invented, the requirement of the new technology may be out of reach of the specific firm or economy, as required in the start-up cost or the size of the plant structure to appropriate the technological innovation. When the new and better technology is too big for the size of accessible market, it cannot be utilized by a small firm or in a small economy[1]. Scale matters with technology adoption policy in developing countries. Small scale investment is the only feasible amount for many developing countries, since they do not have enough resources for large-scale investment. Such developing countries face two problems: (1) unfavorable macroeconomic policy due to a policy maker's bias toward large-scale modern technology, (2) many state of the art technologies requires a large amount of investment at the time of start up. If the would-be adopter has not accumulated enough knowledge and experience, he/she cannot appropriate the new technology fully, either. Therefore, the appropriability of innovative technology belongs to both the nature of the technology and the firm's ability.

Cost and quality of invention evolve

1 Scale matters with technology adoption policy in developing countries. Small scale investment is the only feasible amount for many developing countries, since they do not have enough resources for large-scale investment. Such developing countries face two problems: (1) unfavorable macroeconomic policy due to a policy maker's bias toward large-scale modern technology, (2) many state of the art technologies requires a larg amount of investment at the time of start up.

continuously. Invention itself always improves over time through incremental innovation, and the technological and market environments are continually changing as the demand and supply of the products are interacting with each other. Incremental improvement of innovative product's performance and widely adopted uses of innovated technology also give room to adjust for users for more efficient utilization of innovation.

When these incremental improvements are realized through the lowering of prices of innovative products, so that monetary cost of adoption will decrease.[2)] Greenwood et al. (1997) provide evidence that prices of new equipment have been continuously lowering, and Bass (1980) also shows that prices of durable goods have been decreasing due to the cost reduction and/or due to accumulated experience. On the other hand, these incremental improvements and environmental changes create more uncertainty for the would-be adopting firm, since there is always a possibility that the new competing technology or low-cost improved technology may be available in the near future.

Network externalities reside in both the supply side and the demand side of innovative technology. As one technology is adopted, it takes time and experience to master it. The knowledge producer also invests more resources in the improvement of existing technology rather than replacing the existing one (supply side). Complementary products also follow with the dominant equipment as we have observed in the audio-video industries where setting up the standard of hardware equipment makes compatible software (music CDs, DVD, videotapes) more available (demand side). Thus, network externalities reenforce the increasing return to dominant technology through market interaction (supply and demand). QWERTY keyboard (David, 1985) and nuclear power plant technology (Cowan, 1990; Arthur, 1989) are typical examples where network externalities dominate the adoption of competing technologies.

The technological capability of the would-be adopter is also a prerequisite for fully appropriating new technology. The new adopter may not use the new idea or new technology efficiently with only the general knowledge of it or with a manual of a new machine, unless he/she has accumulated enough experience and localized knowledge from R&D to fully appropriate the new technology (Cohen and Levinthal, 1990 1989)[3)]. In his

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calculation, de la Petterie (1997) reports "all of the other countries (except Japan and the U.S.), the rate of return to direct domestic R&D is not greater than the rate of return to the other traditional inputs"(p. 347). He has also calculated the social rate return that reflects the external effect from R&D on other industries. This implies that some portion of R&D is devoted to the building of absorptive capacity (that is not realized in the Total Factor Productivity measure), since firms do not invest in R&D up to social optimum. However, if the firm's accumulated technology is too localized in a sense that it is not very useful for new technology, newer technology can be costlier than old ones until the firm accumulates enough knowledge for newer technology (Parente, 1994). Therefore, the nature of new technology is also important for the cost of operating with it, if the firm's accumulated knowledge is specific only to the old technology and if the firm's already accumulated knowledge is not useful for the new one.

2) Two Models of Diffusion

The diffusion model has two main components for the diffusion curve formation: population and innovation. In the fixed number of population comprised of potential adopters for a technological innovation, there is a sub-group population that already has adopted this new technology at one point in time. A diffusion curve projects this process of adoption of an innovative technology into a time path that depicts longitudinal change of the adoption group in the population. The major forces that determine the shape of this diffusion curve include the cost and profitability of the specific innovative technology and the communication channels that carry the information about the new product or ide a[4].

Two alternative lines of research materialize the diffusion process in technological innovation[5]. Geroski (2000) provides a through survey on these two models. One is the popular epidemic model that uses the S-shaped diffusion curve, and the other is the probit model where individual decision-maker's heterogeneous

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4 Baptista (2001) suggests a geographical cluster as an influential variable for the diffusion rate. He claims new technological processes may diffuse faster in the geographical areas where the density of sources of knowledge about such technologies is higher since spatial proximity increases the probability of attaining information about new technology and learning about the quality of new technology.

5 Geroski (2000) provides a through survey on these two models.

characteristics for adoption time are considered along with general factors of diffusion.

2-1. Epidemic Diffusion Model

Epidemic diffusion has been used in many diffusion models in economics and other social sciences (Rogers, 1995; Griliches, 1957). Epidemic diffusion has general properties that help one to understand intuitively the shape of the diffusion curve at the expense of missing the detailed decision process about adopting new technology. There are several objectives of the diffusion: new consumer product, new producer product, patented knowledge, and new knowledge without a patent such as the lean production process. There are also several channels to convey the information about these objects.

For the producer of machines into which the newer technology is embodied, advertisement should be limited to a special group of would-be buyers for the intermediate product. This scheme supports the fundamental logic for the endogenous knowledge diffusion, because workers engaged in using a similar machine in an existing company have a better chance of contact with new machines and information about them. A trade organization also helps to spread information quickly and efficiently for the new technology-embodied machinery, because would-be buyers for innovative machines can be contacted easily through a trade organization[6]. Other factors, such as the profit stream from investment based on the cost of purchasing the machine and technological expectation around the specific technology, are also important for the diffusion of a new technology that is embodied into machinery.

For both consumer and producer products, there are two conspicuous channels to induce the diffusion of new products. One is the direct communication channel from sellers to buyers, and the other is the indirect channel between new buyers and potential buyers. The speed of diffusion of a new product depends on the effects from these two communication channels and also on the resistance of the buyer to a new product, the scale of uncertainty about the reward of the new product, and the price of it. These factors

6 Grubel (1993) exposits the importance of industrial (trade) associations such as keiretsus in Japan, bank affiliation in Swiss and Germany, regional agglomeration in the United Statesfor enhancing spillover effect in knowledge and innovation. He exemplifies this industrial association's role for protecting and increasing return from private R&D investment, so that the government subsidy is not mandatory to optimize social welfare from knowledge creation.

influence the shape of the logistic diffusion curve. If the resistance to the innovative product were stronger and if the uncertainty concerning the new product were higher, the speed of diffusion would be slower.

The popular S-shaped diffusion curve is anchored at the simple mathematical relationships among variables. N is the number of potential users of new technology, and $y(t)$ is the number of users who have adopted at time t. The new technology is adopted slowly at the time it is introduced, but the adoption rate increases up to some point before it decrease and fades out as the potential users ($N-y(t)$) deplete. Thus, $y(0)$ is the number of the users at the initial time. A parameter is defined to be the probability that current users meet potential users to give the true information about the new technology that will persuade them to join the cohort of new technology user. This path can be expressed as

$$y(t) = N(1+\phi \cdot e^{-\kappa t})^{-1} \qquad (1)$$

where $\kappa \equiv \beta \cdot N$ and $\phi \equiv (N-y(0))/y(0)$.

The rate of diffusion gradually rises until half the population has adopted it, and then it decreases as the number of nonusers decreases[7]. There is a symmetric density of marginal adoption in the above model. The weakness of this model is that the earlier adopters and later adopters are sharing the same characteristics about the risk of adopting new technology (assumption of heterogeneity of population). The most notable weakness is the problem of ignoring the characteristic differences between an early adopter and a later one. For example, the early adopter may have a more risk-taking attitude than the later one, since the earlier adopter will experience many unknown problems and technological deficiencies because of the relative unknown features of the new technology.

Another unrealistic property of this model, even though it has the merit of model simplicity, is the symmetry of the diffusion function. The S-shaped diffusion model has a symmetric epidemic effect in its diffusion rate, and the rate is the highest at N/2 (up to half of population). However, if we accept the different behavior such that earlier adopters have a more risk-taking character than later ones, then this difference will make it an asymmetric ·diffusion curve. Some factors also aggravate or compensate this problem

7 Quirmbach's (1986) model incorporated the decreasing marginal benefit from new technology adoption in the diffusion function. Therefore, the slow down of diffusion rate is not only from the decreasing population but also from the decreasing the benefit of later adopter in his model.

of the biased diffusion curve depending on the characteristics of product or/and the technology embodied in it. For example, there are earlier comer advantages if the earlier comer can penetrate the newly formed market so that he/she may enjoy a higher market share of the new product introduction, or if he/she can set the standard for the new product in product development so that he/she has an up-start for future innovation. It is hardly possible that other factors will evenly compensate for the difference, which makes a symmetric distribution function appeal[8].

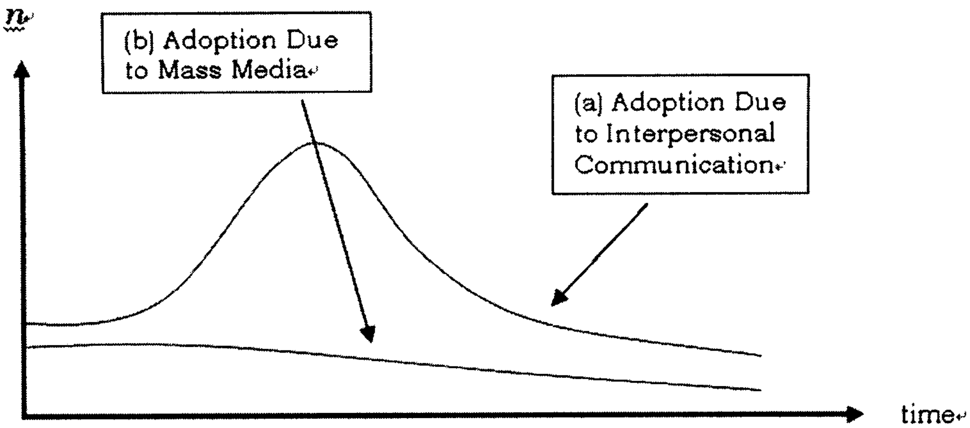
Expected profit, learning, and risk are the main determinants for the speed of diffusion. Available information is obtained through many channels such as learning, observation, commercial advertisement, words-of-mouth flow of information, and so on.

Communication method and easiness of transferring information will also affect the speed of diffusion, so that the densely packed population and early user's enthusiasm for spreading new information will increase the speed. When the would-be adopters receive information about new technology (especially new product) from several channels of acquisition, which is a more realistic paradigm, the distribution of these several channels should be added vertically. Figure 1 shows this relation.

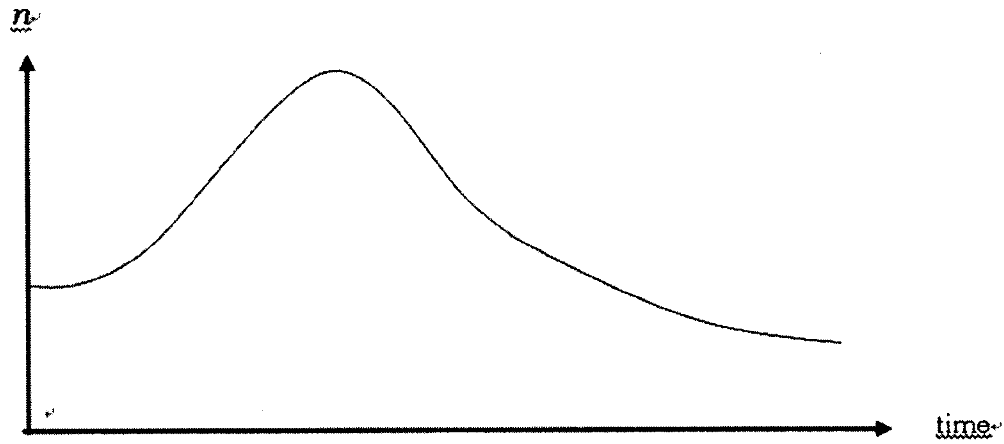
Figure 1 shows the diffusion under the assumption that the information about new product is acquired from two channels: (1) personal communication and (2) commercial advertisement from mass media. Two of these distribution functions are an analytical conceptualization rather than an empirical calculation. Receiving the information about the arrival of a new product from commercial advertisement in mass media has a strong effect for the earlier adopter, but the effect diminishes as time passes. Therefore, the effect of the commercial advertisement is not symmetrical in the time span. On the other hand, the effect from personal communication is distributed as a log normal shape along the whole time span. Figure 1b shows the result of adding-up vertically these two distributions. Figure 1c is a cumulative distribution of Figure 1b.

These graphs show how the diffusion function is shaped in reality, and that symmetric distribution is a very specific example of the diffusion function, even though many researchers frequently adopt the symmetric diffusion function because of its simplicity.

8 Geroski (2000) provides a mathematically feasible modified model for asymmetric cases.



(a) Separate Distributions of Two Sources of Communication



(b) Sum of above Distribution (a) and (b)

2-2. Probit Diffusion Model

The probit model of diffusion is strongly based on the decision to adopt as a choice of a particular individual (or firm)[9].

Even if each individual has received the same external information, each of them may make a different choice due to the heterogeneous characteristics. Considering that adoption is a binary choice, adopt it or not, the threshold value of aggregated variable x* is expected as seen in the Figure 2. The log normal shape of the distribution function (f(x)) shown in Figure 2 is arbitrary. It can be any shape depending on the actual distribution of

9 For the sample of this model, see Colombo and Mosconi (1995) and Karshenas and Stoneman (1993).

individual characteristics in population and the nature of new technology. If ith person's decision variable (xi) about the adoption of new technology is greater than x* (xi>x*), he/she will adopt it. Otherwise, he/she will reject it at the given point of time.

Elements affecting the firm's profitability, risk, and uncertainty are main independent variables for this model of individual decision processing. Since the model is based on the individual decision for the adoption of new technology or embodied technology, the subjective expectation about the future innovation plays an essential part in the decision-making process.

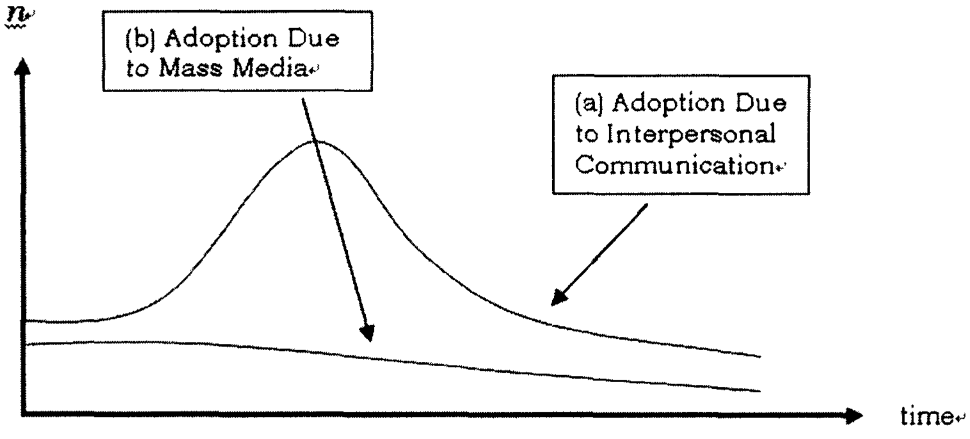
This, in turn, also makes the supplier's decision or strategy an indispensable part of his/her decision process. This is elucidated earlier as the effect of technological expectation by Rosenberg (1976). In the computer industry, for example, the innovativeness of the computer CPU chip determines the computing capability. When a supplier develops faster CPU chips, whether users decide if they will upgrade or not depends on the expectation of arrival time of the next level of CPU chips in the near future. This technological expectation will affect the decision of adoptions through calculating expected price and quality changes, profit stream from immediate upgrade, and so on. The shorter the development time for the next generation CPU chip, the less likely one is to adopt the current chip right away.

Learning and search cost also influence the speed of diffusion. New technology usually comes with a high degree of uncertainty. Many innovations do not appear as a final form when they are first introduced in the market. Continuous minor innovations are expected as the users report the experience of small (sometimes big) problems.

Therefore, the earlier user faces a higher uncertainty that may incur formidable cost in using it. On the other hand, the later user may benefit from the experience that has been accumulated by earlier users. The later user's uncertainty has been reduced, and this will update the expected profitability and cost of adopting the new technology[10].

In addition to uncertainty, switching costs deter the speed of diffusion of a new technology. There are two sides of these switching costs; the first is the nature of new technology. If the new technology is so revolutionary that accumulated

10 This updating rule can be set as Bayesian learning process (Jovanovic and Nyarko, 1996 Jensen, 1982 Stoneman,1981). The risk of adoption (earlier notion of x*) will decrease as the accumulation of user experience increases.



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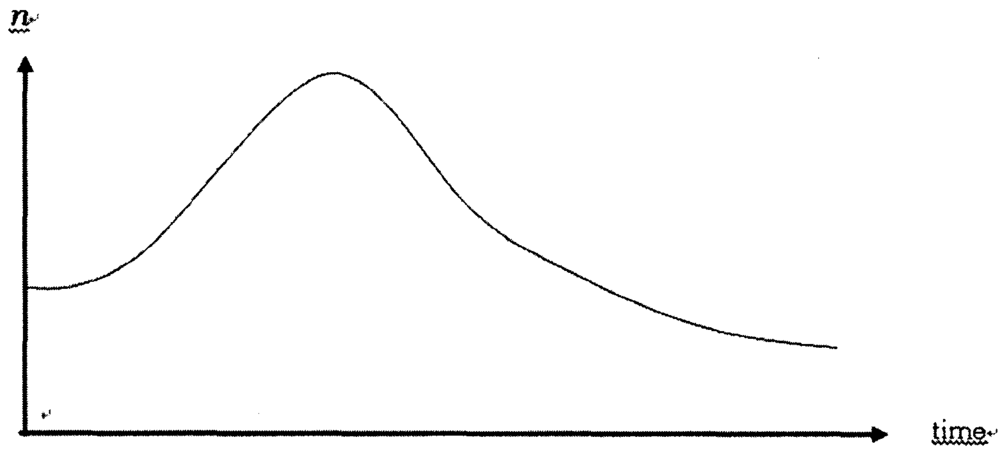

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from journal publications or from a textbook, but a large portion of applicable knowledge requires some preconditions to apply it to the actual production process. However, the adoption of new technology does not always result in acquirement of 'best-practice' technology, because the firm's accumulation from previous 'learning by doing' cannot fully transfer the new technology or because the economy does not have enough skilled workers to adopt a new technology. Technological expectation and network externalities also increase the uncertainty of expected future profit streams from the adoption of innovation by entrepreneurs, and this can lower the adoption rate due to decreased profitability. On the contrary, it is also possible that the positive effect of network externality may increase the rate adoption due to the increasing return to the marginal adoption of a specific technology.

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