

## ENTREPRENEUR AND TECHNOLOGICAL CHANGE

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*The literature on technological change has grown in the last two decades and has made a number of significant theoretical advances, but the role of the entrepreneur in technological change has been relatively ignored. In this paper we attempted to fill this gap and explored the role of the entrepreneur in generating technological change. We constructed an empirical model to analyze the role of the entrepreneur in technological change in the context of deciding the undertaking of the innovation and the commercialization time of the innovation. This model was tested upon a set of data covering 24 innovating firms. The results indicates that the entrepreneur do impact upon the innovation process, and the degree of the impact reaches about two third of what R&D costs impact upon the innovation.*

JEL Classification: O33, O39

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### I. INTRODUCTION

Technological change is, as exemplified in the new growth theory (Romer (1986, 1990)), generally recognized to be a key factor in economic growth. In the new growth theory, technological change is explained in the narrow sense by the advance of knowledge and in the broad sense by the innovation implying one or all of changes in products, processes, raw materials, management methods and markets. By whatever way technological change may be induced, what is missing in the analysis of the new growth theory is about who initiates and implements technological change, i.e. the entrepreneurial role in technological change. Technological change may proceed in response to the market incentive

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as suggested by the standard literature on technological change, but the direction, breadth and speed of technological change may vary, depending upon how the entrepreneur (i.e. the initiator and the implementor of technological change) recognizes and responds to that market incentive. Noting that there have been very few attempts to analyze this entrepreneurial role in generating technological change, in this paper we construct an empirical model to analyze and measure the entrepreneurial role in technological change.

We argue in this paper that the main role of the entrepreneur in technological change is to make 'unprecedented' decisions relating to technological change with 'intrinsic insight' and 'courageous leadership' rather than to create new ideas or to carry out research activities. In undertaking and implementing innovation, there continues to exist technical and commercial uncertainty such as changes in market conditions and in macro economic circumstances, appearance of new technical problems in development process, unexpected rise in R&D costs, the coming of the new products and so on. In the presence of these kinds of uncertainty, decision-making required is about 'stop and go' rather than about 'the optimality calculation' and thus decision making is not of the ordinary routine kind. As Schumpeter (1934) put it, if this kind of decision making is based upon thorough preparatory work, special knowledge, breadth of intellectual understanding and logical analysis, the objective of the entrepreneur is likely to fail. This kind of decision making which may depend on intuition thus reflects the subjective and personal quality of the entrepreneur.

We thus model in this paper a situation where the entrepreneur decides under technological and commercial uncertainties about whether or not to undertake innovation, and once deciding to launch the innovation, when to introduce the innovation into the market. By modelling this kinds of decision, the entrepreneur's role in innovation process can be clearly revealed.

In section II of the paper we discuss more fully the role of the entrepreneur in the innovation process and develop an empirical model to analyze the role of entrepreneur in the context of deciding the undertaking of the innovation and the introduction time of the innovation into the market. This model is tested upon a data set covering 24 innovating firms which commercialised their innovation in 1995, with data and data sources being discussed in section III, estimation method and the results in section IV. In section V, conclusions are drawn.

## II. ENTREPRENEUR AND TECHNOLOGICAL CHANGE

Since J.B.Say had used the term, entrepreneur more than one and half century ago, there were many definitions of 'entrepreneur' offered by many economists. However, these definitions are complementary rather than competitive, in the sense that each definition pays attention to some different feature of the entrepreneurial function. For example, given the generally accepted fact that the entrepreneur is the innovator - the one who transforms inventions and ideas into

economically viable entities, Kirzner (1973) and Mises (1949) regard as a vital function of the entrepreneur the awareness of "unperceived opportunities" in the market and the prediction of, without error, change in future demand respectively, and Schumpeter (1934) sees as a qualification for the entrepreneur the leadership, once finding an opportunity, to put the opportunity into practice.

We think that the entrepreneurial functions given by different economists simply represent the roles of the entrepreneur required in each stage of initiating, implementing and diffusing innovation. Below we explore in more detail the role played by the entrepreneur in each stage of innovation process.

### **2.1. The Role of Entrepreneur in Generating Innovation**

In general, the process of innovation can be divided into three stages (see Marquis (1966), Horsmans (1979)). The first stage, which we call 'the initiation stage', is when the need for innovation is recognised, then availability of technology for innovation and the likelihood about commercial success of innovation are searched and assessed, and finally the decision on whether or not to launch innovation is made. All the process in this stage proceeds on the initiative of the entrepreneur : he grasps 'unexploited future opportunities' and he ultimately makes decision about the launching of innovation. It is here worth noting that entrepreneur's decision-making is based not upon systematic calculation but upon instinct, inspiration and vision. Hence, as Kirzner (1985) puts it, the function exercised by the entrepreneur in this stage is to instinctively be aware of commercial and technological opportunities, present and future. The second stage of innovation named as 'the implementation stage' is when R&D activities for innovation are carried out. The entrepreneurial role in this stage is to finance R&D activities and, if necessary, to carry out new resource allocation (including rearrangement of organisation) for efficient R&D activities. These activities requires the entrepreneur 'leadership' as a special kind of function, because he sometimes need to convince or impress the banker and participants in R&D activities by creating confidence about his plan. In this stage, after major R&D efforts begin, he also makes a series of decision-makings : R&D activities typically takes many years over this period and he may face unexpected change such as rise in R&D costs, coming of a better product and change in consumer taste, etc. In this case, he must make decisions about stop-and-go, speed of R&D activities, change in R&D investment, timing of product introduction and so on. The third stage (i.e. the diffusion stage) is when the innovation is introduced and diffused into the economy. The entrepreneur's role in this stage is minimal in terms of 'the Schumpeterian innovator'. Once the innovation is introduced into the market, continuing processes are by and large about routine pricing and advertising outlay decisions, which are activities for manager rather than entrepreneur.

To summarize, the entrepreneur's main role in generating innovation is to be

aware of 'unexploited opportunities' and 'change in the future' and makes decisions on launching of innovation, R&D investment, timing of product commercialization, stop-and-go and etc. under technological and commercial uncertainty. As Baumol (1993) puts it, this kind of decision is realistically made, based upon intuition rather than optimality calculation. The entrepreneur's courageous and instinctive decision making in innovation process is an important factor in making innovation, which we shall model in the next section.

## 2.2. The Model

In the above section, we argue that the entrepreneur's main role for innovation is to be aware of commercial and technological opportunities and transform these opportunities into commercially viable products. We will attempt to model this entrepreneur's role in this section, but as Baumol (1993) put it, it is not easy to model or prove quantitatively entrepreneur's role in generating innovation. We need, in one way or another, to find a way of modelling and proving the entrepreneur's role. Since the entrepreneur's role such as grasping commercial and technological opportunities or organizing R&D activities is reflected in entrepreneur's decisions such as on launching of innovation, R&D investment and so on, we believe that the entrepreneur's role can be properly dealt with a 'typical decision theoretic model'.

In order to model the entrepreneur's role for innovation within the framework of a decision theoretic model, we select the commercialization timing of innovation as the entrepreneur's key decision variable. The reason why the commercialization timing of innovation is selected as a key decision variable is that the decision on commercialization time requires the consideration of all the variables relating to innovation and thus through endogenizing commercialization time, the entrepreneur's role for innovation can be properly modelled. For example, as shown in equation (2) below, when the entrepreneur considers the commercialization timing of an innovation, he has to know about the expected returns and R&D costs of that innovation, which he would not know without being aware of commercial and technological opportunities in the markets. Hence, as the entrepreneur knows better about commercial and technological opportunities in the market, he can select a higher-profit producing commercialization time. Likewise, as he engages more in organizing R&D activities or implementing innovation, he can select a higher profit-producing commercialization time. Following this observation, the entrepreneur's role such as grasping 'unexploited future opportunities' in the innovation process or organizing R&D activities is modelled by the decision process of the commercialization time.

Define the annual gross profit gain to firm  $i$  in calendar time obtained from introducing innovation  $j$  to the market at time  $t$  as  $g_{ij}(\tau)$ , determined as<sup>1</sup>

<sup>1</sup> Reflecting industry characteristics of firms in our sample (see the mean of K1 and K2 in

$$g_{ij}(\tau) = g_j(q_i(\tau), P_j(\tau), K(\tau), S_i(\tau)) \quad (1)$$

where  $q_i$  is the output of firm  $i$ ,  $P_j$  the price of innovation  $j$ ,  $K$  characteristics of the industry to which firm  $i$  belongs,  $S_i$  characteristics of firm  $i$  (throughout, unless essential, the  $i$  subscript will be dropped to simplify notation) and the partial derivative designated as a subscript are signed as  $g_q > 0$ ,  $g_p > 0$ ,  $g_k < 0$  and  $g_s < 0$ .

Defining  $r$  as the discount rate or interest rate, we may then write the net present value of innovation  $j$  commercialised at time  $t$ , evaluated at time 0 to be

$$Z(t) = \exp(-rt) \left\{ - \int R(t) dt + \int g(\cdot) \exp(-r(\tau-t)) d\tau \right\} \quad (2)$$

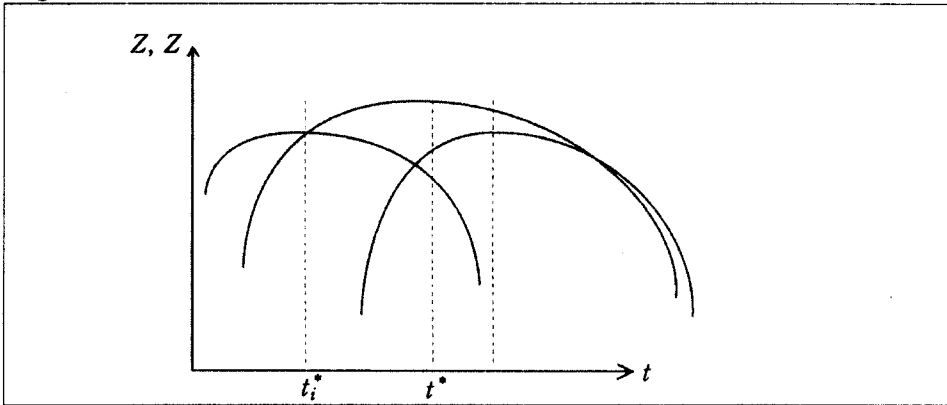
where  $R(t)$  is the annual R&D investment incurred for innovation  $j$ .

In general, the entrepreneur decides to undertake R&D activities for innovation if and only if  $Z(t) \geq 0$ . This decision is obvious in the Arrow-Debreu world where all agents correctly forecast changes in the future markets and thus correctly calculate the future gross profit from innovation. However this is not what is observed in reality. Although there may exist the objective probability on R&D costs and profits from innovation which is based upon the accumulated data, there are still a lot of unpredictable factors which cannot be objectively and numerically assessed but which still influence R&D costs and profits. Hence the net present value of innovation  $j$  at time  $t$  can be various, depending upon what the decision makers subjectively assess for such unpredictable factors (see Savage (1954) for the discussion of subjective probability). As we discussed above, entrepreneurs carry out a special kind of function to assess such unpredictable factors from 'alertness, instinct, hunch and inspiration', even though there are still differences in subjective assessment among entrepreneurs, depending upon the result of differences in information and in confidence about their role in innovation process. Following this observation, we define the net present value of innovation  $j$  commercialised at time  $t$  and assessed by entrepreneur  $i$  at time 0 to be

$$Z_i(t) = P(x) \cdot \left\{ \exp(-rt) \left[ - \int R(t) dt + \int g(\cdot) \exp(-r(\tau-t)) d\tau \right] \right\} \quad (3)$$

where  $P(x)$  represents the subjective numerical odds that entrepreneur  $i$  assesses on the net value of innovation realised over the infinite time horizon, which depends on the degree of his (expected) involvement into the innovation process (i.e., initiation and implementation stage), ' $x$ '. We assume that the subjective numerical odds are  $-\infty \leq P(x) \leq \infty$  in the relevant range of  $x$ .

[Figure 1]



In the Arrow-Debreu world,  $Z(t)$  of equation (2) (i.e., the ex-ante net value of innovation  $j$ ) is not different from the ex-post net value of innovation  $j$  and therefore in this world, an economic agent correctly chooses the optimal commercialization time ( $t = t^*$ ) maximising the net value of innovation  $j$ . However, in practice, entrepreneur's subjective assessment on  $Z(t)$  ( $Z_i(t)$ ) is different from  $Z(t)$  of equation (2) and thus he chooses the commercialization time,  $t$  which is not the point of time maximizing the net value of innovation  $j(t^*)$ . Given that entrepreneur's main function is to be aware of 'unexploited opportunities' and 'changes in future', it can be, however, said that he chooses as the commercialization time the point of time which is not very far from the optimal commercialization time,  $t^*$  (see Figure 1). We here assume that entrepreneur is able to choose  $t$  nearer to  $t^*$  as he becomes more involved in the innovation process :  $P(x) \rightarrow 1$  as  $x$  increases.

Entrepreneur  $i$ 's decisions on the undertaking of innovation and the commercialization time of innovation are determined by dynamic optimality conditions (see Dixit (1989)) : the profitability condition and the arbitrage condition. The first we may interpret as that innovation must yield positive profits, and the second condition requires that the net profit from innovation is not increasing over time. (i.e. waiting before commercialization of innovation  $j$  is not profitable). Since the arbitrage condition dominates the profitability condition (Ireland & Stoneman (1985)), it is sufficient to check only the arbitrage condition for entrepreneur's decision on both the undertaking of innovation and the optimal timing of introduction of the innovation. Assuming that (1)  $Z_i(t^*)$  has an interior maximum at  $t = t^* \leq \infty$  and thus  $\partial Z(t)/\partial t \geq 0$  for  $t \leq t^*$  and  $\partial^2 Z(t)/\partial t^2 < 0$ , the arbitrage condition is specified as (4)

$$Y_i = \partial Z_i(t)/\partial t \leq 0$$

$$= P(x) \cdot \{r(t^*)CR(t^*) - cr(t^*) - g_j(q(t^*), P_j(t^*), K(t^*), S(t^*))\} \leq 0 \quad (4)$$

where  $CR(t^*) = \int R(t)dt$  and lower case letter (eg,  $cr(t)$ ) represents derivatives with respect to time.

If we assume away corner solutions, the strict equality of (4) holds

$$Y_i(t) = P(x) \cdot \{r(t)CR(t^*) - cr(t^*) - g_j(q(t^*), P_j(t^*), K(t^*), S(t^*))\} = 0 \quad (5)$$

Equation (5) states that in terms of the subjective assessment of entrepreneur  $i$  ( $P(x)$ ), the optimal timing ( $t^*$ ) of commercializing innovation  $j$  is determined at the time that the net benefit from waiting further before commercialization of innovation  $j$  is equal to the net cost of waiting.

Stoneman and Kwon (1995, 1996) argue in their models that the above framework may exclude the factors which may influence the model. Thus, we incorporate such factors into the model by an error term  $e_i$ , which is assumed to be randomly distributed and independent of  $Y_i$ , with a cumulative distribution function  $F(\cdot)$  and a probability density function  $f(\cdot)$ . The optimal adoption date then satisfies (6)

$$Y_i(t^*) + e_i = 0 \quad (6)$$

Using (6) we may then derive the 'hazard rate' about the commercialization time of innovation  $j$ <sup>2</sup>. That is, the probability of entrepreneur  $i$  commercializing innovation  $j$  in the interval  $(t, t+dt)$ , which is conditional upon it not having commercialized innovation  $j$  prior to time  $t$ , the **hazard rate**,  $h_i(t)$  can be written as (7)

$$h_i(t) = \text{prob}(Y_i(t) + e_i < 0) = F(-Y_i(t)) \quad (7)$$

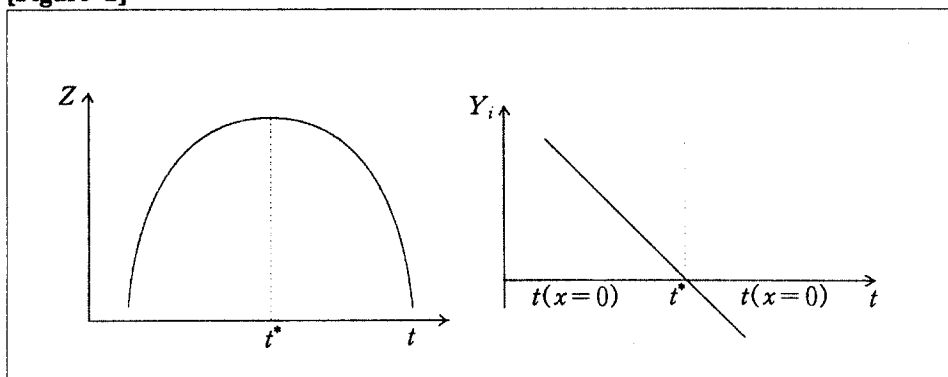
Approximating  $Y_i(t)$  by a linear function, we may then write (7) as (8) :

$$h_i(t) = H(x, r(t)CR(t), cr(t), q(t), p_j(t), K(t), S) \quad (8)$$

From (1) and (5) we may see that  $Y_i(t)$  is positively related to  $rCR(t)$  and negatively related to  $q(t)$ ,  $P_j(t)$  and indeterminate with  $x$ ,  $cr(t)$ ,  $K(t)$  and  $S$ . The relationships between  $Y_i(t)$  and all other variables than  $x$  and  $cr(t)$  are obvious, and thus here we clarify only the relationship between  $Y_i(t)$  and  $x$ , and  $Y_i(t)$  and  $cr(t)$ . First, we assumed in the above that  $P(x)$  approaches 1 (i.e.,  $t$  approaches  $t^*$ ) as  $x$  increases. This implies as shown by Figure 2 that

<sup>2</sup> The reason why we derive the 'hazard rate' from (6) is to (1) reflect uncertainty intrinsically existed in technological change and to (2) avoid the endogeneity between the dependant variable and the explanatory variables in the empirical model developed later on.

[Figure 2]



as  $x$  increases,  $Y_i(t)$  either decreases or increases, depending upon whether  $t$  at  $x=0$  lies at the left side or the right side of  $t^*$ . In the absence of detailed knowledge on the position of  $t$  at  $x=0$ , we become a priori agnostic as to the sign of the impact of  $x$  on  $Y_i(t)$ . Second,  $cr(t)$ , the expected change in R&D costs in the foreseeable future can go in either direction. If R&D costs decrease over the interval  $(t, t+dt)$ ,  $Y_i(t)$  and  $cr(t)$  are positively related, and vice versa. We thus become a priori agnostic as to the sign of the coefficient of  $cr(t)$ . Given that  $F$  is a decreasing function in  $Y_i$ , we may predict that  $h_x < 0$ ,  $h_{rCR} < 0$ ,  $h_{cr} < 0$ ,  $h_q > 0$ ,  $h_{pj} > 0$ ,  $h_k < 0$ , and  $h_s < 0$ . Equation (8) provides the basis for estimation.

### III. MEASUREMENT, DATA SOURCES, AND DATA

#### 3.1. The measurement of Variables : Entrepreneurial Role, Firm and Industry Characteristics

The entrepreneur's role in innovation is not easy to measure quantitatively, and thus we proceed by using the rating along a five-point scale by highlevel R&D executives of innovating firms on questions about the entrepreneur's role : we asked each respondent to give a rating along a five-point scale about the following questions<sup>3</sup> : (1) the role of the entrepreneur in recognising the need of innovation, (2) the degree of participation by the entrepreneur in assessing the expected profitability of innovation in the initiation stage, (3) the degree of involvement by the entrepreneur in selecting one of available technologies for innovation, and (4) the role of the entrepreneur in deciding the commercialization time

<sup>3</sup> In the questionnaire, the entrepreneur is defined as a top executive(s). A top executive represents an owner and manager for 13 small and medium sized firms and a chief director for 11 subsidiary firms of large business groups. Whether a top executive is an owner and manager or an employed chief director, he seems to be a final decision maker on innovation.

of innovation. We regard the first three questions and the last question as the role of the entrepreneur in the initiation and implementation stage respectively, and thus used the mean of the ratings for the first three questions as a single variable measuring the role of the entrepreneur in the initiation stage.

We specified in equation (1) that the annual gross profit gain obtained from innovation depends on firm and industry characteristics. Following the standard technological change literature, we measure firm size (measured by total sales) and R&D employees as firm characteristics and two kinds of industry dummies as industry characteristics. It is worth noting that the market structure or the degree of competition typically used for the measurement of industry characteristics cannot be used in our model, because all innovating firms capture the monopolistic position from innovation. We thus specify as industry characteristics two industry dummies representing the existence of the similar product in domestic and foreign markets and one industry dummy representing the attribute of the product (i.e., component, capital goods or consumer goods).

### 3.2. Data and Data Source

In order to estimate equation (8), we collected the data from the firms which received 'Jang Young Sil award' in 1995. 'Jang Young Sil' award is given to the successfully innovating firm by strict screening (52 firms a year). We asked 52 firms a question about whether or not they can reveal some information relating to their innovation. 24 firms readily agreed to give the information relating to their innovation, and thus we obtained the data on period of R&D, total amount of R&D investment, sales of innovation, price of innovation, and the rating on the entrepreneur's role in the innovation etc. by visiting and interviewing high level R&D executives of the innovating firms. Table 1 summarizes the details of firms in the sample.

The firms in the sample are distributed among 11 sectors, and their size measured by total sales ranges from 10.5 billion Won to 25.4 trillion Won<sup>4</sup>. Their average commercialization time taken from the initiation stage is 36 months with a standard deviation of 7.07. The shortest commercialization time is 7 months for the wireless pager and the longest time is 94 months for the vehicle engine. The firms in the sample spent on average 20.98 billion Won (26.2 million US \$) for innovation with standard deviation of 65481  $e+06$ . High R&D executives give the average rating of 3.94 and 3.87 for the entrepreneur's role in the initiation and implementation stages respectively (the rating ranges from 1 (not at all) to 5 (very positive role)). This implies that entrepreneurs intervene more

<sup>4</sup> We examined the distribution of firm size in more detail in order to check potential sample selection bias resulting from the inclusion of only successfully innovating firms. Given the fact that larger firms are more likely to succeed, it may suspect that our sample may comprise larger firms. However, our examination reveals that 9 firms (38 %) out of 24 firms in our sample are even smaller than the average size of 'medium sized firms' in the manufacturing sectors.

**[Table 1]** Distribution of Firms

ID of firm	Innovation	Industry	TYPE of the Product
1	Fan attached in Air-Conditioner	Electrical Engineering	Intermediate Goods
2	Television Set	Electrical Product	Consumer Goods
3	Washing Machine	Electrical Product	Consumer Goods
4	Diamond Coating Head Drum	Mechanical Engineering	Intermediate Goods
5	1.8 DOHC Engine	Motor Vehicles	Intermediate Goods
6	Gartelcom	Tele-Communication	Capital Goods
7	Robot	Mechanical Engineering	Capital Good
8	Portable Ultrasonic Diagnostic Instrument	Medical Instrument	Consumer Goods
9	Digital Alarm	Electrical Engineering	Capital Goods
10	Nylon Film	Chemical	Intermediate Goods
11	Word Processor Software	Computer Software	Consumer Goods
12	Plastic Goods	Chemical	Intermediate Goods
13	CD ROM	Computer Hardware	Consumer Goods
14	Water Purifier	Instrument Engineering	Intermediate Goods
15	Wireless Pager	Electrical Product	Consumer Goods
16	Cement	Cement	Intermediate Goods
17	Word Processor Software	Computer Software	Consumer Goods
18	Video Tape Machine	Mechanical Engineering	Capital Goods
19	Word Processor Software	Computer Software	Consumer Goods
20	Sewage Cleaning	Bio Chemical	Capital Goods
21	Medicine	Bio Chemical	Consumer Goods
22	Washing Machine	Electrical Product	Consumer Goods
23	Excavator	Mechanical Engineering	Capital Goods
24	Vehicle Engine	Motor Vehicles	Intermediate Goods

positively in the initiation stage of the innovation than in the implementation stage.

#### 4. Estimation Methods and Results

In order to estimate equation (8), we used a Cox Proportional Hazard Model in which the explanatory variables are all non-time varying variables. Software package STATA was used for estimation, and definitions of explanatory variables, sample statistics and the estimates are presented in Tables 2,3, and 4.

Looking first at the diagnostic tests, the likelihood test rejects over the specified explanatory variables the hypothesis that all coefficients in regression are zero at the 99% significance level. LM test rejects the hypothesis of heteroscedasticity at the 99% significance level. We also examined correlation among explanatory variables. The degree of multicollinearity among explanatory variables is, in general, very low. The only exception is between  $q$  and Size (0.86). Since multicollinearity enlarges the variances of coefficients, we dropped Size variable from the estimation.

**[Table 2] Definitions of Explanatory Variables**

Variable	Definition
$t$	= The commercialization time, measured by the period (month) from the initiation of innovation to introduction of the innovation into the market
$X_1$	= The rating on the entrepreneur's role in the initiation stage $1(\leq X_1 \leq 5)$
$X_2$	= The rating on the entrepreneur's role in the implementation stage $1(\leq X_2 \leq 5)$
$r(t)CR(t)$	= The interest rate in 1995 times total R&D costs (millions Won) incurred between the time of initiating innovation and 1995
$cr(t)$	= The difference in CR between $t$ and $t+1$ , measured by change in CR in 6 months
$q(t)$	= Output of innovation in 1995
$P_j(t)$	= The price of innovation in 1995 (thousands Won)
$K_1$	= Industry dummy: one if there exists the similar product with innovation in the foreign markets, zero otherwise
$K_2$	= Industry dummy: one if there exists the similar product with innovation in the domestic market, zero otherwise
$K_3(4,5)$	= Industry dummy: one if the innovation is component, (capital goods, consumer goods), zero otherwise
Size	= Total sales of innovation in 1995 (millions Won)
RE	= The Number of R&D employees in 1995

**[Table 3] Sample Statistic of Variables RE**

Variable	Mean	Standard Deviation	Variable	Mean	Standard Deviation
$t$	36.6	26.05	$K_1$	0.91	0.28
$X_1$	3.94	0.86	$K_2$	0.41	0.5
$X_2$	3.87	1.07	$K_3$	0.25	0.44
$CR$	20983	65481	$K_4$	0.29	0.46
$cr$	1845	4775	$K_5$	0.45	0.5
$Q$	876	2438	RE	32.5	67.3
$P_j$	40801	97282	Size	1122280	5174821

The coefficients in Table 4 may be classified into three groups representing entrepreneur's role in the innovation process, the costs of innovation and the benefits from innovation. We proceed to discuss the hypothesis tests about the statistical relationship between the probability of commercializing the innovation at any point of time and coefficients of each group.

The coefficients of the variables that represent the entrepreneur's role are significant at the 90% level and carry a positive sign for  $X_1$  and a negative

[Table 4] Maximum Likelihood Estimates of Cox Proportional Hazard Model

Variable	Prediction	Coefficient ( <i>t</i> -value)
$X_1$	< > 0	1.36 (1.72)*
$X_2$	< > 0	-1.84(-2.31)**
$CR$	< 0	-0.001(-3.69)**
$cr$	< > 0	0.04(3.22)**
$Q$	> 0	-0.0004(-2.19)**
$P_j$	> 0	-2.4 e-06(-0.71)
$K_1$	< 0	-2.72(-2.07)**
$K_2$	< 0	-0.58(-0.73)
$K_4$	< > 0	4.98(2.81)**
$K_5$	< > 0	2.41(2.26)**
$RE$	> 0	-0.18(-3.24)**

Log -Likelihood ratio :  $\chi^2 = -36.96$

Number of observation : 24

$\chi^2$  test for coefficients of  $X_1$  and  $X_2 = 0$  :  $\chi^2(2) = 5.62$

$\chi^2$  test for coefficients of  $CR$  and  $cr = 0$  :  $\chi^2(2) = 13.53$

$\chi^2$  test for coefficients of  $K_1$ ,  $K_2$ ,  $K_3$  and  $K_4 = 0$  :  $\chi^2(4) = 10.59$

$\chi^2$  test for coefficients of  $q$ ,  $p_j$ ,  $K_1$ ,  $K_2$ ,  $K_3$ ,  $K_4$  and  $Re = 0$  :  $\chi^2(7) = 12.34$

\*\* : 95% significance level

\* : 90% significance level

sign for  $X_2$ . The hypothesis ( $X_1 = 0$  and  $X_2 = 0$ ) that the entrepreneur do not impact upon the commercialization of innovation (implicitly the speed of R&D, R&D costs, R&D investment and the benefits from innovation) is rejected at the 90% level by  $\chi^2$  test. One may thus reasonably conclude that the entrepreneur does impact upon the innovation process. Our data also reveals that the initiative by the entrepreneur in the initiation stage accelerates the commercialization of the innovation, but the entrepreneur's participation in the implementation stage slows down the introduction of the innovation into the market. This may reflect the fact that most innovations in our sample were developed over the period of a slough in the business cycle during 1992-1994.

The variables representing R&D costs are significant at the 99% level and carry the coefficients of the expected signs. This implies that the commercialization of the innovation is less likely to happen the greater the R&D costs. Also, the plus sign of the coefficient of  $cr(t)$  indicates that, if the entrepreneur has perfect foresight, the rise of R&D costs over the period of innovation leads to increase the probability of commercializing the innovation.

The variables related to the benefits obtained from introducing the innovation carry the mixed signs of coefficients. All the variables other than  $K_2$  representing industry characteristics are significant at the 95% level and carry the coefficients of the expected signs, but  $q$ ,  $P_j$  and  $RE$  carry the wrong signs

although  $q$  and RE are significant. To assess the overall impact of the benefits from the innovation on the commercialization time, we test the hypothesis that all the determinants of  $g(\cdot)$  do not impact upon the commercialization of the innovation.  $\chi^2$  test rejects that hypothesis at the 90% level. Hence we conclude that the benefits from innovation also impact upon innovation.

In summary the results indicate that :

(i) the approach to modelling the entrepreneur's role as an insightful decision maker in uncertain innovation process has validity, and this entrepreneur's role proved to be vital for the innovation.

(ii) R&D costs and change in R&D costs are influential determinants in deciding both the undertaking of the innovation and the introduction time of the innovation.

(iii) Industry characteristics including the existence of the similar products and the type of the innovating product are influential in innovation process, but firm characteristics and price of innovation at the commercialization time do not impact upon the innovation.

Lastly, to quantify the impact of the entrepreneur's role on the innovation, we calculate the elasticity of 'the probability of commercializing the innovation' with respect to the proxy variables about the entrepreneur's role in the innovation process<sup>5</sup>. The estimate is 0.35 (the estimates are 0.15 for  $X_1$  and 0.2 for  $X_2$  respectively) and is nearly two third of the elasticity with respect to R&D costs (0.57). With the above qualitative result, this figure suggests that the entrepreneur is important for innovation and that any model of technological change that exclude the entrepreneur may well suffer from misspecification.

## 5. Conclusion

The literature on technological change has grown in the last two decades and has made a number of significant theoretical advances, but the role of the entrepreneur in technological change has been relatively ignored. In this paper we attempted to fill this gap and explored the role of the entrepreneur in generating technological change. We constructed an empirical model to analyze the role of the entrepreneur in technological change in the context of deciding the undertaking of the innovation and the commercialization time of the innovation. This model was estimated upon a set of data covering 24 innovating

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<sup>5</sup> The elasticity is calculated by multiplying the average value of the variable concerned and the absolute value of the coefficient of that variable.

firms. The estimates indicate that the probability of commercializing the innovation (which is implicitly related to the essential issues of the innovation such as R&D investment, the speed of R&D and the expected benefits from the innovation) is related to (i) the role of the entrepreneur in the innovation process, (ii) R&D costs and (iii) the net returns from innovation. These results indicate that entrepreneurship is one of the major factors in the determination of technological change and thus deserves to receive greater attention than it has received in the literature to date.

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