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Technological Characteristics by Industry and Innovation Strategy

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Abstract This aim of the study is to show the necessity of implementing an industrial innovation strategy with consideration given to characteristics of the industrial technology. The relationship between industrial technological characteristics and innovation performance is analyzed by using an innovation survey as well as a human capital corporate panel (HCCP). The time-lag effect is also examined. Findings of the analysis show that high-tech industries have entered the post catch-up technology innovation stage in the mid-2000s, but low-tech industries still seem to stay in the catch-up stage. In terms of technology policy, the additional technology innovation support policy should focus on enhancing the innovation capability of the middle and low technology industries, since high technology industries are already developing their own innovation capability. It is necessary to strengthen capacity building through technical cooperation with technology consulting, rather than providing technical support through suppliers.

Keywords Industrial technological characteristics, industrial innovation strategy, source of innovation, patent application

I. Introduction

Korea has succeeded in establishing a catch-up innovation system through imitation and improvement of advanced technology in the process of industrialization until 1990s. However, in the 2000s, since the technological and economic competition environment changed, a new innovation system beyond the catch-up system was demanded. According to Hwang et al. (2012), the concept of catch-up is a concept of process of transition, and catch-up innovation focuses on the ability to produce based on expansion through the acquisition, use and upgrade of imported technology. On the other hand, post

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catch-up innovation includes the development of new product concepts and new innovations that create a new industrial trajectory.

In addition to discussing the post catch-up innovation strategy, this study proposes a differentiation of innovation strategies according to the technical characteristics of industries. Analyzing the patent applications over 10 years as a measure of innovation achievement, we show the internal and external cooperation of firms as sources of innovation at the firm level. In a previous study, Hwang et al. (2014) analyzed the sources of corporate technology innovation by differentiating between high-tech industries and low-tech industries. In both types of industries, internal innovation sources have positive effects, although the effects of external technology sources are inconsistent in the mid-to-low technology industry and the high-technology industry. Further, the study failed to show statistical significance.

We examine the innovation performance in the low-tech industries and the high-tech industries and the effect of time difference. The data are common data from the Human Capital Enterprise Panel (HCCP) survey conducted in 2007 by Hwang et al. (2014), as well as the corporate innovation survey carried out by the Science and Technology Policy Institute in 2005 and 2006. We also added the patent applications until 2015.

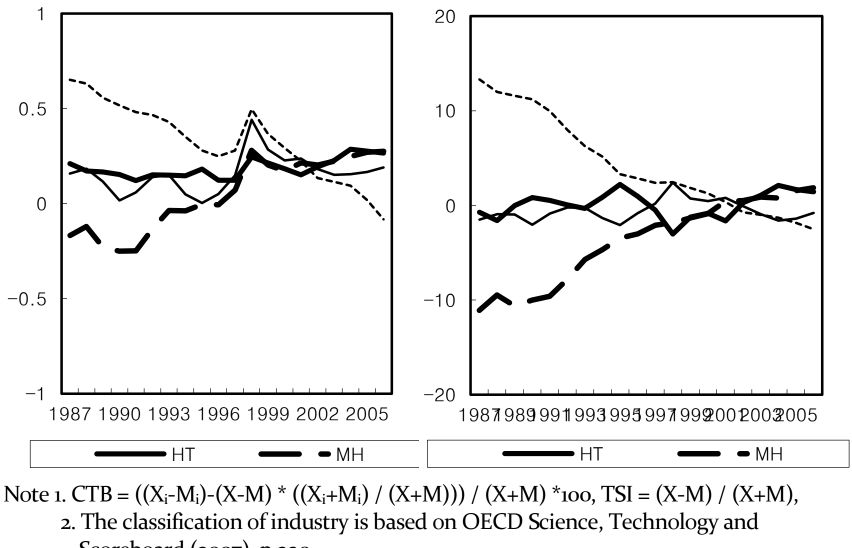
In section 2, we discuss the differences in sources of technological development between high-tech industries and low-tech industries, the time lag, and whether collaboration with outside companies affects innovation performance at the theoretical level. Section 3 examines the nature of the analytical data and the negative binomial distribution model that considers these data. Chapter 4 presents an analysis and interpretation of results, and Chapter 5 discusses the findings and limitations of the study.

II. Theoretical Discussion

1. Difference of Sources for Development between Industries

In the mid-2000s, during the transition to the post catch-up period in Korea, the difference in technological development between high-tech industries and middle-low technology industries and the difference in the source of technology development are considered to be closely related to the difference in technology development stage. Using OECD (2007) criteria, Jeon (2009) examined the export competitiveness of each industry by classifying the industries into four categories: high-tech, middle-high technology, middle-low technology and low technology.

According to Jeon (2009), the export competitiveness of low-tech industries has been declining steadily since the 1990s, while the export competitiveness of high-tech industries has increased. This suggests that there may be differences in the level of technology as well as export competitiveness between low-tech industries and high-tech industries in Korea. In other words, while middle-low technology industries are still in the technological learning phase of the imitator, high-tech industries have already entered a post catch-up technological innovation system with improvement in the product, process innovation, and new product development in the early 2000s. As a result, the low-tech industries still accumulate internal technology capabilities through R&D investment, while external technology sources also play an important role in innovation. On the other hand, since the high-tech industries have entered the post catch-up technology innovation system, the internal technology source through R&D can be more important than the external technology source. Several scholars, such as Huang et al. (2010), Rammer et al. (2009) and Barge-Gil (2010) pointed out that external knowledge sources and collaboration with external partners such as customers, suppliers and competitors can make innovation success (Hwang and Lee, 2015).



Note 1. CTB = $((X_i-M_i)-(X-M) * ((X_i+M_i) / (X+M))) / (X+M) *100$, TSI = $(X-M) / (X+M)$,
2. The classification of industry is based on OECD Science, Technology and Scoreboard (2007), p.220.
Source: Jeon (2009), p.39.

Figure 1 Export competitiveness by technology level

2. Time Lag from the Source to Innovation Performance

In the case of capital investment, it may take some time from test operation to main operation, but it generally increases the profitability of firms by increasing productivity within a short period of time. However, in the case of R&D investment, the investment may not necessarily lead to performance (uncertainty).

Branch (1974) analyzed the effect of R&D of 111 companies in seven US industries during 1950-1965 and reached the conclusion that R&D is affected by past profits, which impact on future profits. In this analysis, time lag was assumed to be four years, because it takes nine months from innovation to patent application and 3.5 years from patent application to registration (Branch, 1974). In Korea, Lee (1997) and Hong et al. (1991) did not use a statistical analysis, but carried out an empirical study using average time lag by industry found in the literature survey.

Some studies have estimated directly the time lag between R&D investment and patent performance. Wang et al. (2014) analyzed the time lag between R&D investment and patent application on multi-national pharmaceutical companies over the period 1986-2000 using the multiplicative distributed lag model and the dynamic linear feedback model. Results of this study show that R&D investment over the current and past period is the most influential factor in linking R&D investment to the number of patent registrations. Further, long-term effects also indicate that the process of knowledge production and innovation is cumulative.

Lee et al. (2014) estimated the time lag between R&D investment and patent application by using panel data of 1,055 companies from the R&D Activity Survey (2002-2009) by the Korea Institute of Science and Technology Evaluation and Planning and the patent database of the Korea Intellectual Property Organization. In particular, Almon's parallax distribution model was applied to five industries – chemical, metal and metal processing, electric and electronic, precision science, and other machine manufacturing. The result points to the fact that the time lag between R&D investment and patent application is two years, although there are some differences among industries. However, these studies did not analyze the effect of R&D investment on patent applications or filings, but only confirmed the time lag to patent applications and filings.

3. Cooperation with Outside Innovation Performance

Lee, Park and Bae (2016) analyzed the effect of external knowledge exploration activities on the innovation productivity of 901 firms having intensive R&D activities and export concentration of less than 1 in The Technology Innovation Survey from the Science and Technology Policy Institute. The results of this study are as follows: the extent of search for external knowledge and market-based search are the influential factors for the productivity of low-technology firms. On the other hand, science-based search is reduces the productivity of low-technology firms. The depth of search has no statistical significance.

In this study, we classify the industry into high-tech and low-tech industries and examine how external technology sources and R&D investments affect patent applications and what the time lags are.

III. Data and Model

1. Distribution of Dependent Variables

The data used in this study are the information from 122 companies that overlapped with the 2007 Human Capital Companies Panel (HCCP) Survey by the Korea Vocational Training Institute and the 2005 and 2006 Technology Innovation Survey by the Korea Institute of Science and Technology Policy. We combine the financial information from Korea Credit Rating Co. (2002-2006 sales and R&D data), from these companies, from patent information (applications) provided by the 2016 HCCP, and from the technology innovation information extracted from the Technology Innovation Survey.

The patents are applications utilizing the DB information (2007- 2015) by the Korean Intellectual Property Office provided through the HCCP. Figure 2 shows the frequency distribution. There are 14 companies without patent application, 37 companies with 1 to 10 applications, 45 companies with 11 to 100 applications, and 26 companies with 101 and more applications. This distribution is considerably different from the regular distribution with long tales on the right-hand side. Figure 2 is not the distribution with the same interval, but it shows the long tale on the right-hand side. This distribution gives a rationale for considering the Poisson distribution and negative binomial distribution.

While the average and variance differ significantly, 469.4 patent applications averaged over the period 2007-2015, with 172.7 over the 2007-2009 period, 154.2 and 142.4, respectively, falling between 2013 and 2015.

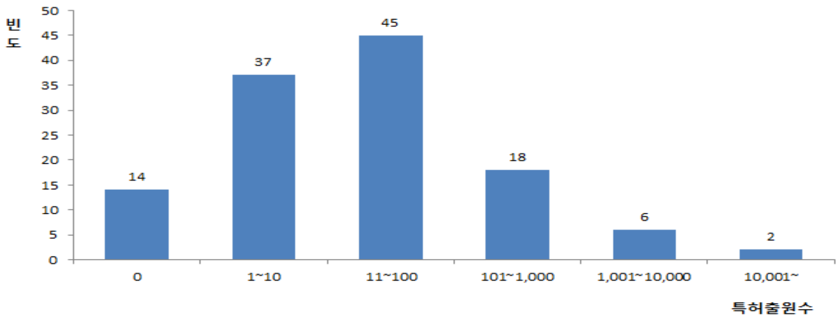


Figure 2 Patent applications in Korean Intellectual Property Office (KIPO) (Accumulated number during 2007-2015)

Table 1 Statistics of patent application

Period	Firm no.	Average	S.D.	Min	Max
Total	122	469.4	2103.7	0	17,328
2007~2009	122	172.7	973.7	0	10,157
2010~2012	122	154.2	691.9	0	5,132
2013~2015	122	142.4	606.3	0	5,507

2. Analytical Model

Although the Poisson regression model requires equidispersion such as E(Y) = Var(Y), the current distribution shows over-dispersion E(Y) < Var(Y). Therefore, the negative binomial distribution is more suitable to this distribution. On the other hand, if the density of 0 is considered to be high, a zero-inflated negative binomial (ZINB) model may be applied, but the current distribution is not regarded as zero excess. If the ZINB is used, the Vuong Test is applied (Vuong, 1989).

In this analysis, the number of patents is a dependent variable, and the independent variables are the importance of technology acquisition and cooperation from business firms for technology and consulting (B_TechCo), vendors of raw materials, parts, S/W, and service (S_TechCo), and the importance of marketing and sales as an in-house information source for technological innovation (Sales). In addition, we use R&D ratio (RD) and scale of company (Size) since both of them influence patent applications. As for the group difference, the high-tech industry (h) and the low-tech industry (l) are analyzed separately.

$$Patent=NB\ (RD,Size,BTechCo,STechCo,Sales) \qquad (1)$$

In order to distinguish the time lag from the sustainable effect to the patent application by period, we separated the data during 2007 to 2009, 2010 to 2012, and 2013 to 2015, respectively, with the transformation to root value.

3. Data

Pavitt (1984) identified the difference between industries by size, the purpose of innovation and the sources of innovation, and classified industries into four types: supplier-dominated industries, scale intensive industries, specialized supplier industries, and science-based industries. At this time, supplier-dominated industries are classified as low-tech industries, and the optimization of process technology is regarded as a key technological innovation.

The OECD (2002, 2005) classifies industries by R&D intensity: high-tech industries with the intensity of more than 4%, medium-tech industries with 1 - 3.9% intensity, and low-tech industries with the intensity of less than 1%.

Classification	Standards of Industry Classification
High-tech industry (HT)	Medical materials and pharmaceuticals, electronic components Computer video sound and communication equipment, medical precision optics and watches, electrical equipment, manufacturing of other machinery and equipment, vehicles and trailers
Medium-low technology industry (LMT)	Food, beverages, textiles, apparel accessories and fur products, Leather bags and shoes, wood and wood products, pulp paper and paper products, Printing and recording media duplication, coke briquetting and oil refining product, Chemicals and Chemical products, rubber and plastic products, non-metallic mineral products, Primary metal ,Metal-processor products, Other transit transport equipment, furniture, Other products (musical instruments, precious metals, etc.)

Source: Sung (2005)

In Korea, Sung (2005) classified the industries as high-tech industries with more than 2% R&D intensity and low technology industries with less than 2.0%, with 2.0% as the industry average. In the middle and lower technology industries, innovation activity seems to be relatively slow because innovation activity through internal development is relatively small compared to that of high technology industry.

According to the classification by Sung (2005), the 122 companies that overlapped with the HCCP Survey in 2007 and the Technology Innovation Survey in 2005 and 2006 are as follows: 73 companies are in high-tech industries and 49 companies are in mid- and low-technology industries.

Table 2 Data by industry and by employment size

		300↓	300~999	1000~1999	2000↑	Total
Medium-low technology industry	Beverage food	2	2	1	4	9
	Cloth/ fur	5	1	0	0	6
	Petrochemistry	7	7	1	0	15
	Rubber / plastic	2	0	0	0	2
	Metallic / non-metallic	8	7	4	3	22
High-tech industry	Machinery	5	5	0	0	10
	Electricity	6	4	0	0	10
	Electronics	7	10	2	1	20
	Traffic equipment	1	12	2	0	15
	Telecommunication	0	1	0	1	2
	SW/SI/On-line DB	6	3	1	1	11
Total		49	52	11	10	122

Since the number of companies in each cell is very limited, it is difficult to examine the average number of patent applications (2007-2015), but the average number of patents in high-technology industries is bigger than in low-technology industries. In the petrochemicals sector, however, the number of patent applications is lower than in high-tech industries, but higher than the average in the middle-low technology industries.

In this study, we focus on the ratio of R&D to sales, technology acquisition and cooperation with business (technology, consulting), supplier (raw material, parts, software, service), and internal sources (marketing and sales) for technological innovation, as the factors affecting patent applications.

In-house information sources for technology acquisition, cooperation and innovation were extracted from the Technology Innovation Survey. The 2005 survey concerned manufacturing, and the 2006 survey concerned the service industry. Therefore, we used the 2005 survey. In the original survey, the industries were surveyed as interval scales, but they were reconstructed in this study. The negative answer[1] was 0 for the degree of importance and innovation contribution and 1 for positive answer. In the case of multiple responses (technology acquisition and technical cooperation), we put 1 if the question includes at least a 1, and 0 if all the answers are 0.

Table 3 Patent application by industry and employment size

		300↓	300~999	1000~1999	2000↑
Low-medium technology industry	Beverage food	9	11.5	79	24.8
	Cloth/ fur	3.6	1		
	Petrochemical	24.3	44.1	3407	
	Rubber/ plastic	6			
	Metallic /non-metallic	13.3	24.4	200.3	7194.7
High-tech industry	Machine equipment	241.2	867.4		
	Electricity	49.3	394.3		
	Electronics	35.6	76.3	16	17,328
	Traffic equipment	46	113.9	502	
	Telecommunication		7		450
	SW/SI/On-line DB	87.7	25.7	665	533

In-house information sources for technology acquisition, cooperation and innovation were extracted from the Technology Innovation Survey. The 2005 survey concerned manufacturing, and the 2006 survey concerned the service industry. Therefore, we used the 2005 survey. In the original survey, the industries were surveyed as interval scales, but they were reconstructed in this study. The negative answer[2] was 0 for the degree of importance and innovation contribution and 1 for positive answer. In the case of multiple responses (technology acquisition and technical cooperation), we put 1 if the question includes at least a 1, and 0 if all the answers are 0.

Technology acquisition and technology cooperation through business firms (technology and consulting) averaged 0.279; through suppliers (raw materials, components, software, and services) it averaged 0.352, and internal information source (marketing and sales) is 0.669. On the other hand, the ratio of R&D to sales revenue is based on the last five years' average from the

[1] Positive answer is the answer of more than 3 and negative answer is the answers with less than 3 and no use or no experience.
[2] Positive answer is the answer of more than 3 and negative answer is the answers with less than 3 and no use or no experience.

financial information from Korea Credit Rating Co., provided by the 2007 HCCP survey. The R&D ratio to sales revenue is up from 11.1% to at least 0%, with an average of 1.7%.

2005 Technology Innovation Activity Survey Table

6.1 As a source of information used during the early or intermediate stages of your innovation activities during the past three years, how important were the following items?

Source of information	No use	Importance Low←				→High
Marketing and sales sectors (E108)	0	1	2	3	4	5
Research department (Attached/Central) (E 109)	0	1	2	3	4	5

7.2 Who are the acquired technology sources? And how useful was the external technology information to your technology innovation?

Technology acquisition source	No use	Innovation Contribution Not at all←				→Extreme
Supplier (raw material, parts, software, service) (F22)	0	1	2	3	4	5
Business companies (technology, consulting) (F19)	0	1	2	3	4	5

8.2 Please rate the extent to which your partners have contributed to your innovation activities over the past three years.

Cooperation partners	No	Innovation Contribution Not at all←				→Extreme
Supplier (raw material, parts, software, service) (F53)	0	1	2	3	4	5
Business companies (technology, consulting) (F50)	0	1	2	3	4	5

Table 4 Explanatory variables extracted from the Technology Innovation Survey

Variable description		No of 2005 Survey
Technology acquisition and cooperation	Business companies (technology, consulting)	F19, F50
	Suppliers (raw materials, parts, software, services)	F22, F53
Sources of Internal Information for Technological Innovation	Marketing and sales sectors	E108

Table 5 Basic statistics of explanation variable

Variable		Mean	S.D.	Min	Max
R&D / Sales		0.017	0.022	0	0.111
Technology Acquisition and Cooperation	Business companies	0.279	0.450	0	1
	Suppliers	0.352	0.480	0	1
Internal information sources		0.689	0.465	0	1

IV. Results

As a result of applying the negative binomial distribution to the number of patents filed by 49 medium-low-tech companies and 73 high-tech companies, the ratio of sales to R&D and the size effect have a positive effect, as expected. The effect from internal information (marketing and sales) is not statistically significant.

Medium-low tech industries and high-tech industries show differences in technology cooperation effects (business firms, suppliers). In the medium-low tech industries, there are split results: a positive (+) effect of business partners (technology and consulting) and a negative effect of supplier technology cooperation (2007- 2015, 2007- 2009). There is no statistical significance of the technical cooperation effect in the high-tech industries.

Comparisons between the coefficients of explanatory variables by period show more interesting results. The effect of R&D on sales is increasing after a certain point and then decreases with statistical significance3. On the other hand, the effects of technology acquisition and technical cooperation are decreasing and the statistical significance disappears over time.

Technology acquisition and technical cooperation effects are significant only in the low-tech industries. Technology cooperation with business firms (technology and consulting) is decreasing from 1.803 in 2007-2009, 1.289 in 2010-2012, and 1.138 in 2013-2015. The effect of supplier technical cooperation in the low-tech industries also tends to decline from -1.482 in 2007-2009 to -0.774 in 2010- 2012 and -0.447 in 2013- 2015. However, the statistical significance is confirmed only for the 2007-2009 period.

[3] In low-tech industry, the coefficient of the ratio of R&D/sales increases to 0.459 in 2010-2012, and decrease to 0.371 in 2013-2015. In high-tech industry, the ratio increases to 0.258 in 2010-2012 and decreases to 0.217 in 2013-2015.

Table 6 Results

Medium-low-technology industry		PATENT 0715		PATENT 0709		PATENT 1012		PATENT 1315	
Explanatory variable		Coef.	S.D.	Coef.	S.D.	Coef.	S.D.	Coef.	S.D.
Constant		0.681	0.431	0.181	0.477	-0.370	0.546	-0.059	0.523
R&D / Sales (%)		0.417***	0.154	0.459	0.171***	0.528***	0.188	0.371**	0.182
Size effect (More than 300 = 1)		1.582***	0.361	1.607	0.432***	1.866***	0.430	1.672***	0.426
Technology acquisition and cooperation	Business companies	1.240**	0.521	1.803	0.657***	1.289**	0.607	1.138*	0.587
	Suppliers	-0.759*	0.449	-1.482	0.584**	-0.774	0.526	-0.447	0.504
Internal Information	Marketing and sales sectors	-0.027	0.401	-0.252	0.478	0.227	0.472	0.025	0.467
Dispersion		1.130	0.251	1.334	0.355	1.369	0.341	1.501	0.380
Deviance	D.F	1.2393		1.1751		1.1827		1.2062	
Pearson Chi-Square	D.F.	1.8614		1.4608		1.9048		1.4629	
Number of Samples		49							

High-tech industry		PATENT 0715		PATENT 0709		PATENT 1012		PATENT 1315	
Explanatory variable		Coef.	S.D.	Coef.	S.D.	Coef.	S.D.	Coef.	S.D.
Constant		0.934***	0.285	0.173	0.299	0.254	0.366	0.453	0.383
R&D / Sales (%)		0.202***	0.057	0.222***	0.054	0.258***	0.077	0.217***	0.083
Size effect (More than 300 = 1)		0.875***	0.298	1.063***	0.291	0.701*	0.391	0.652	0.417
Technology acquisition and cooperation	Business companies	0.246	0.392	0.052	0.414	0.136	0.509	0.497	0.501
	Suppliers	0.301	0.420	0.075	0.426	0.780	0.559	0.718	0.565
Internal Information	Marketing and sales sectors	-0.062	0.307	0.142	0.304	-0.288	0.399	-0.476	0.426
Dispersion		0.982	0.183	0.865	0.180	1.549	0.340	1.769	0.380
Deviance	D.F.	1.2223		1.1761		1.1844		1.1665	
Pearson Chi-Square	D.F.	1.1354		1.3012		0.8759		0.7971	
Number of Samples		73							

Note: *** within 1%, ** 5%, * 10%.

V. Implications and Limits

The results of this analysis are summarized as follows:

Regarding technology innovation sources, there is a difference in technology innovation sources between the medium-low technology industries and the higher technology industries. The R&D and size effect have positive effects, but the effect of technology acquisition and cooperation differs between the middle-low- technology industries and the high-technology industries. In the high-technology industries, the statistical significance of the technology acquisition and cooperation effect is not secured. In the middle- and low-technology industries, however, the effect with business companies is positive, and that of supplier is negative.

This means that the technological innovation capacity of the high-technology industries must be met internally, while external technology cooperation is an important issue in the middle- and low-technology industries. However, the negative effect of suppliers is interpreted as showing a possibility of technology dependency. As for the effect of each variable, differences in effect by time lag are interesting in comparison to coefficients for explanatory variables. The R&D effect is achieved with a 5-to-8 year time lag, while the external technology cooperation effect is decreasing over time.

The findings of this study show that the high technology industries have entered the post catch-up type of technology innovation system in the mid-2000s, but the middle-low technology industries are still in the catch-up stage. Here, meaning of the post catch-up type of technology innovation system is that there is the internal source of innovation. Similarly, existence in the catch-up stage means that the source of innovation is still external.

In particular, it is possible that the development of self-innovation capacity may be suppressed by relying on suppliers, especially in the case of the low-tech industries. If we consider technology policy area, additional policies should focus on enhancing the innovation capacity of the middle- and low-technology industries. At this time, rather than providing technical support through suppliers, it is necessary to strengthen their own innovation capacity through technical cooperation and technology consulting.

This is a study of the early stages of the post catch-up period in the mid-2000s. If the analysis is done on the basis of a time lag of 5-8 years of innovation performance presented in this study, it will be possible to track the progress of the post catch-up. This may be a topic for new research. Another fundamental limitation of the study is limited number of observations, 122 companies only. It might influence the ambiguity of statistical significance and further prevent the complicated analysis with control variables such as technology level, financial characteristics etc. To solve the limitation, the better data set is necessary and remained to the future research.

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