Chapter 91
Gaming of Green Supply Chain Members Under Government Subsidies—Based on the Perspective of Demand Uncertainty

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Abstract With the rapid development of global economy, the demand of natural resources is increasing rapidly, and the depletion of natural resources and environmental protection are becoming more and more serious. The implementation of the green supply chain management can achieve the win-win situation of economic and environmental benefits, truly enhance the core competitiveness of enterprises and promote economic sustainable development, which becomes the important direction of the implementation of national sustainable development strategy. Aiming at the characteristics of uncertainty demands in consumer market, Based on the government subsidy function and Stackelberg model, the paper constructs a three level green supply chain system which including manufacturers, suppliers and customers, and analyzes the incentive mechanism on the decision-making and profit of the supply chain members. With the help of Matlab 7.0, the arousal effect of government subsidies and the lower limit of greenness are analyzed. The results show that: by increasing the intensity and access threshold of subsidies, the government can stimulate the demands of consumer market and reduce the adverse effects to the manufacturers and suppliers because of the risk of demand uncertainty.

Keywords Green supply chains · Government subsidies · Gaming models · Demand uncertainty

91.1 Introduction

With the rapid development of the world economy, the traditional manufacturing business have created a lot of material wealth for human beings, but the resources shortage, greenhouse effect and other environmental problems caused by it can not be ignored. How to maximize the utilization of resources and reduce the negative impact on the environment has become an increasingly important issue for scholars

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and governments at home and abroad. In order to alleviate pressures caused by various economic activities, the relevant laws and regulations have been established by every country to bring environmental protection into the daily management and strategic decision of enterprises. But the efforts of individual enterprises can not effectively improve the conflict between enterprises and the environment in whole market, and the green supply chain management is a new management mode to solve this problem. The concept of green supply chain was first proposed by the research group "Environmentally responsible manufacturing" in manufacturing Research Institute of Michigan State University in 1996 [7], combined with the relevant literature, this paper defines the green supply chain as: throughout environmental protection awareness into the entire product life cycle process, which contains product design, manufacturing, packaging, transportation, use and disposal, and finally consult out green products through the green design, green materials, green packaging, green recycling and other technical means, so all enterprises in supply chain can achieve mutual profits and make the least negative impact on the environment [9]. As a super manufacturing country, resource waste and environmental destruction events occur frequently in China, so improving the green supply chain management is particularly important. To promote enterprises carrying out the green supply chain work, Chinese government developed a series of incentives, such as the energy-saving products project jointly promoted by the national development and Reform Commission, Ministry of industry, Ministry of Finance in 2009, giving financial subsidies to air conditioners, refrigerators, washing machines and other ten types of energy-saving products which efficiency standard over one or two level. In order t offset the rising cost of R&D and production of energy-saving products. Because of the strong support of the government, the supply chain will develop in the direction of the green supply chain, and the members of the supply chain will carry out game in the green supply chain management. In order to study the situation, that is, the strategic choice of the green supply chain members when the demand is uncertain, this paper builds a Stackelberg game model, which is used to study the decision-making problem of the manufacturers and sellers in the green supply chain.

91.2 Literature Review

In recent years, domestic and foreign scholars' research on the green supply chain management mainly has the following several aspects: (1) The relationship between green supply chain management and enterprise performance. Using the questionnaire, Ye [10] built the structural equation model to analyze the relationship between product green design and enterprise performance. Results showed that the external competitors and policies regulations have a significant positive impact on the green design. Green design can significantly increase the environmental performance and economic performance. Using grey correlation evaluation method, Yi [2] conducted transverse and longitudinal analysis to green supply chain management performance of four steel enterprises. The results showed that, from 2005 to 2010, green supply

chain management level of the four steel enterprises raise gradually. Mirhedayatian [6] also studied on the economic performance and environmental performance of the green supply chain by using the DEA model under the pressure of the relevant policies regulations. (2) Driving factors analysis of green supply chain management. Su [8] used confirmatory factor analysis method to investigate the main factors affecting green technology cooperation between enterprises in supply chain, results showed that the characteristics of enterprise green technology, the external environmental pressure, dependencies between upstream and downstream enterprises of supply chain all have a greater effect to green technology cooperation, which are basically the same with most of the existing research results. (3) Comparison analysis of the traditional supply chain and the green supply chain. Jin [4] set up a game model composed of ordinary products and green products, and analyzed the model optimal equilibrium solution in a variety of situations, gained the optimal decision-making of enterprise and the government's optimal incentive policy. (4) Research on the relationships of main parts in green supply chain. Li [5] conducted evolutionary game model and analyzed the enterprises' emission reduction behavior under government supervision. The model pointed out that government can choose to supervise or not, enterprises can choose whether to implement the green supply chain, given the costs and benefits of the enterprises' low carbon production, government supervision and taxation, and obtained the evolutionary stable strategy of different situations. Considering the underpowered problem of current enterprises' green cooperation, Zuo [12] researched the relationship between cluster supply chain green cooperative behavior and government regulation. Results showed that: the waste's production scale, waste re-use fixed investment, raw materials procurement prices are prerequisite to cluster supply chain green cooperation; government's fines to waste discharge, government's regulatory costs, government's reputation loss incurred by supervision dereliction all have a varying degrees impact on cluster supply chain green cooperation. From the standpoint of stochastic output, Zeng [11] studied the incentive mechanism of government subsidies to green supply chain system composed by manufacturer and retailer, through the mathematical method, and analyzed the stochastic output factors' influence to supply chain members' decision and profit. Jiang [3] established four green supply chain game model: Stackelberg game model dominated by manufacturer, Stackelberg game model dominated by seller, Nash equilibrium game model and centralized control model. Jiang [3] carried out the comparative analysis to four kinds of game models in terms of product green degree, product price and wholesale price, and established the game model under revenue sharing contract.

According to the documents, it is found that research on the influence of product greenness on supply chain members' decision making is relatively less while considering the demand uncertainty and government subsidies at the same time. So under the premise of an uncertainty demand on green products, this paper builds a game model of green supply chain consisting of manufacturers, sellers and consumers. So we can provide theoretical support for manufacturers and retailers in green supply chain management.

91.3 Model Description and Assumption

To promote a class of green products, expand consumer demand, improve energy efficiency and promote industrial upgrading, the government invested a certain amount of funds, considering to give subsidies to the products whose greenness are more than g_0, we called the floor level of greenness, the government subsidy coefficient for per product is r, and the consumer demand q is an uncertain function. To produce green products manufacturers need to assume a certain additional cost, that is, unit marginal cost will increased by λ on the basic of the initial ordinary product cost c, but also need to pay a certain R&D costs I. Because the market demand is uncertain, so we assumed the expected value of actual sales volume is s. At the same time considered surplus products' residual value h. In this paper, we consider the three-level of green supply chain composed of a single manufacturer, retailer and customer, in which the manufacturer is in the dominant position, and the government offer subsidies to manufacturers according to the greenness of the product. Supply chain decision-making process is as follows: after subsidy policy to green products is issued by government, manufacturers will first make decisions about product greenness g_m and product wholesale price in order to achieve the maximization target interests, in the observation to the manufacturer's decision, sellers will determine green product's ordering quantity. Specific variables are described as follows:

p : Seller's unit product price;
w : Seller's unit product cost, that is, the manufacturer's unit wholesale price;
h : Surplus products' residual value, $p > w > h$;
q : Consumer demand, which is a function of the uniform distribution between 0 and a, $q \sim [0, a]$;
$f(x)$: The probability density functions of consumer demand, $f(x) = 1/a$;
$F(x)$: The probability distribution function of consumer demand, $F(x) = x/a$, $x \in [0, a]$;
y : The products number that seller actually ordered from the manufacturer;
g_m : The product's greenness level, this paper believes that the green degree level is continuous;
c : Unit marginal cost of the manufacturer's ordinary products, there are $w > c$;
g_0 : Minimum subsidy level of greenness, $g_m > g_0$;
I : Manufacturer's R&D costs;
λ : Assume there is a linear correlation between increased unit cost and greenness, The product cost coefficient $\lambda = \varepsilon(g_m - g_0)$;
t : unit product's subsidy coefficient adjustment factor;
r : Government subsidy coefficient to per unit of sales products, $r = t(g_m - g_0)$;
π_1 : Manufacturer's profit function;
π_2 : seller's profit function;
S : Expected value of actual sales volume when seller's ordering quantity is y, $S = \int_0^y xf(x)dx + \int_y^\infty yf(x)dx = y - \int_0^y F(x)dx$

There is a dynamic multi game between green supply chain members, under the condition of not changing the problem nature, the model do the following assumptions:

Hypothesis 1: government subsidy program has been determined, that is, subsidy coefficient to per unit of sales products and the level of greenness have been determined;

Hypothesis 2: game process only considers the problems between manufacturer and distributor, sellers and consumers. It is considered that the manufacturers, sellers and consumers are limited rational economic men, and aimed at maximizing their self-interest;

Hypothesis 3: customers have no preference for the greenness of the product, only influenced by the product price and market capacity;

Hypothesis 4: referencing the classic A-J model in Technology Management, which considered there exists quadratic relation between R&D results and R&D investment [1]. So in this paper, we think there exists quadratic relation between manufacturer's fixed cost and greenness level: $I = \beta(g_m)^2$.

Called β is the fixed investment cost coefficient and assumed that the value of β can guarantee the existence of the equilibrium solution of the game.

Based on the above assumptions, we obtain that:

Manufacturer's profit function:

$$\pi_1 = (w - c - \lambda + wr)\, y - 1. \tag{91.1}$$

Seller's profit function:

$$\pi_2 = ps + h\,(y - s) - wy. \tag{91.2}$$

91.4 The Game Model of Green Supply Chain Under the Government Subsidy

In the green supply chain management, considering the uncertainty of demand, product greenness, government subsidies and other factors, the paper establishes a Stackelberg game model of manufacturers and retailers: the first stage, manufacturer develops production strategy according to the government's subsidy policy, and determines product's greenness g and product's wholesale price w; second stage, seller determines the order strategy and product order quantity y according to the manufacturer's decision-making and market demand information. The following model is solved by using backward induction method.

First, we should analyze seller's decision behavior, by substituting actual sales of green products into the formula (91.2); we get the formula (91.3):

Seller's profit function:

$$\pi_2 = (p - w)y - (p - h)\int_0^y F(x)dx. \tag{91.3}$$

Take partial derivative of π_2 with respect to y, we can get:

$$\begin{cases} \frac{\partial \pi_2}{\partial y} = p - w - (p - h)F(y), \\ \frac{\partial^2 \pi_2}{\partial y^2} = -(p - h)f(y). \end{cases} \tag{91.4}$$

Because the product price is greater than the residual value, so $\frac{\partial^2 \pi_2}{\partial y^2} < 0$, formula (91.4) is a decreasing function, we can get:

$$\begin{cases} \frac{\partial \pi_2}{\partial y}_{y=0} = p - w - (p - h)F(0) = p - w > 0, \\ \frac{\partial \pi_2}{\partial y}_{y=\infty} = p - w - (p - h)F(\infty) = h - w < 0. \end{cases} \tag{91.5}$$

So there is bound to be an order quantity that makes formula equal to zero, and at this time the sales profit is the maximum value. Based on this, we can get the formula (91.6):

$$y^* = F^{-1}\left(\frac{p - w}{p - h}\right). \tag{91.6}$$

Secondly, we should analyze manufacturer's decision-making behavior. By substituting obtained y^* into formula (91.1), and due to the assumption of market demand is a uniform distribution function between 0 and a, so the probability density function of consumer demand $f(x) = 1/a$ and the probability distribution function of consumer demand $F(x) = x/a$, then manufacturer's profit function π_1 becomes formula we get the formula (91.7):

$$\begin{aligned} \pi_1 &= (w - c - \varepsilon(g_m - g_0) + wt(g_m - g_0))F^{-1}(\frac{p - w}{p - h}) - \beta(g_m)^2 \\ &= (w - c - \varepsilon(g_m - g_0) + wt(g_m - g_0))\frac{a(p - w)}{p - h} - \beta(g_m)^2. \end{aligned} \tag{91.7}$$

Take first order partial derivative of pi_1 with respect to w and g, we can get formula (91.8):

$$\begin{cases} \frac{\partial \pi_1}{\partial \omega} = \frac{a(p - w)(1 + t(g_m - g_0))}{p - h} - \frac{a(w - c - \varepsilon(g_m - g_0) + wt(g_m - g_0))}{p - h}, \\ \frac{\partial \pi_1}{\partial g_m} = \frac{a(p - w)(wt - \varepsilon)}{p - h} - 2\beta g_m. \end{cases} \tag{91.8}$$

Take second order partial derivative of with respect to w and g, we get the formula (91.9):

$$\begin{cases} \dfrac{\partial^2 \pi_1}{\partial {g_m}^2} = -2\beta, \\ \dfrac{\partial^2 \pi_1}{\partial \omega^2} = -\dfrac{2a(1+t(g_m - g_0))}{p-h}, \\ \dfrac{\partial^2 \pi_1}{\partial \omega \partial g_m} = \dfrac{\partial^2 \pi_1}{\partial g_m \partial \omega} = \dfrac{atp - 2atw + a\varepsilon}{p-h}. \end{cases} \tag{91.9}$$

So $\dfrac{\partial^2 \pi_1}{\partial \omega^2} < 0$, $\dfrac{\partial^2 \pi_1}{\partial {g_m}^2} < 0$, and we get the Hessian Matrix:

$$\begin{vmatrix} \dfrac{\partial^2 \pi_1}{\partial \omega^2} & \dfrac{\partial^2 \pi_1}{\partial g_m \partial \omega} \\ \dfrac{\partial^2 \pi_1}{\partial \omega \partial g_m} & \dfrac{\partial^2 \pi_1}{\partial {g_m}^2} \end{vmatrix} > 0. \tag{91.10}$$

After calculating we found Hessian matrix is negative definite, so the manufacturer's profit is a concave function on greenness and the wholesale price, that is to say, there exist an optimal wholesale price w^* and greenness g_m^* to make maximum the value of manufacturer's profit. Then substitute w^* and greenness g_m^* to make maximum the value of manufacturer's profit. Then substitute w^* and g_m^* into formula (91.7), we can get seller's optimal order quantity y^*.

91.5 Example Analysis

91.5.1 Analysis Under the Variation of Government Subsidy

In order to analyze the influence on decision-making of manufacturers and sellers, under the variation of government subsidy, at the same time observe whether a greater subsidy will promote green supply chain members to produce high greenness products. Let unit product's subsidy coefficient adjustment factor t varies in [0.15, 0.6] and other parameters unchanged ($a = 100$; $p = 80$; $g_0 = 1$; $c = 50$; $h = 30$; $\varepsilon = 1$; $\beta = 50$). By using Matlab 7.0, this paper calculates the approximate solution of each formula. The calculation results are shown in Table 91.1.

As can be seen from the Table 91.1, with the increase of subsidy adjustment factor t, product's greenness g_m is on the rise, and when $t > 0.2$, the product wholesale price w continue to reduce, the seller's order quantity y further increase, manufacturers and sellers' expected profit were increased. This means that the government subsidies can greatly mobilize the enthusiasm of manufacturers to develop green products, and decreasing wholesale price lead sellers gradually replace the market

Table 91.1 Numerical analysis to government subsidy coefficient adjustment factor t

t	w	g_m	t	π_1	π_2
0	74.4444	−0.1111	11.1111	283.3351	30.8647
0.05	75.5883	0.2452	8.8235	204.259	19.4631
0.1	75.9873	0.5296	8.0254	169.6235	16.1018
0.15	74.7938	1.064	10.4123	208.3681	27.1045
0.2	69.0109	2.8137	21.9783	532.2987	120.7603
0.25	63.6949	4.8666	32.6101	1144.1451	265.8563
0.3	60.2303	6.749	39.5394	2007.059	390.841
0.35	57.9252	8.5093	44.1496	3119.3846	487.2968
0.4	56.3274	10.1939	47.3451	4475.9399	560.392
0.45	55.1783	11.8301	49.6434	6071.6638	616.1168
0.5	54.3254	13.4343	51.3492	7902.7428	659.1851
0.55	53.6753	15.0164	52.6494	9966.4111	692.9898
0.6	53.1684	16.5825	53.6632	12260.7214	719.9348

share, while consumers can buy green products with a cheaper price, so green supply chain which considered government subsidy can reduce the sales price of green products, stimulating consumption, improve the market share of green products, and increase the profits of enterprises, promote R&D and innovation of green technology, and finally improve the market competitiveness of enterprises. However, compared with the situation that without government's subsidy policy ($t = 0$), when the government subsidy coefficient adjustment factor is low (such as $t < 0.2$), the wholesale price of green products is higher and manufacturer and seller's profit is lower than before. This result indicates that, in order to better play the role of government participation, encourage manufacturers to develop green technology and green products, the government subsidies should reach a certain level, which is not only can ensure a more manufacturers revenue, but also can reduce the sales price of green products, so manufacturers, sellers and customers can benefit together, which also increased the management performance of green supply chain.

However, a too high subsidy adjustment factor will not only lead to a larger financial subsidy burden, but also prone to the phenomenon of excessive dependence on government subsidies, once the government subsidies decline or stop, manufacturers may be caught in a loss state. For example, ZHIGO Company always relies on subsidies to energy-saving air conditioning; in 2009 its total profit is more than 3 billion Yuan, however, after the subsidies policy adjustment to energy-saving in 2010, CHIGO Company's interim report display that it has stepped into a state of loss. Which means that, in order to promote the industrial structure adjustment, the government needs to set up a scientific and reasonable adjustment factor.

91.5.2 Analysis Under the Variation of Government Subsidy

In order to describe the impact that variation of g_0 on the supply chain, let g_0 varies range 0 to 1.6, the government's subsidy adjustment factor $t = 0.6$, the other variables are constant, Figs. 91.1, 91.2, 91.3 and 91.4 respectively describe the variables change

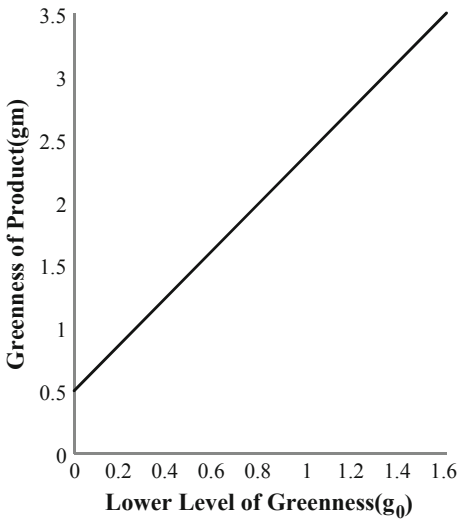

Fig. 91.1 Effect of the variation of g_0 on g_m

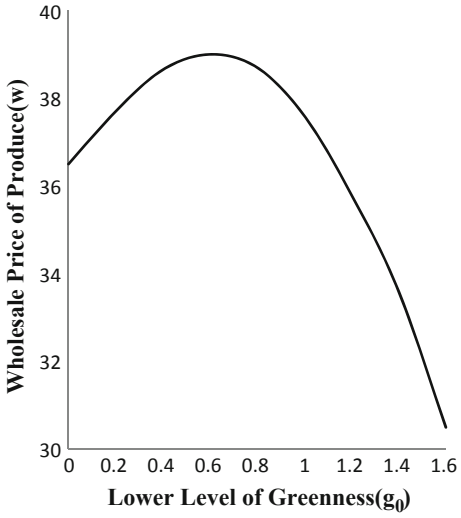

Fig. 91.2 Effect of the variation of g_0 on w

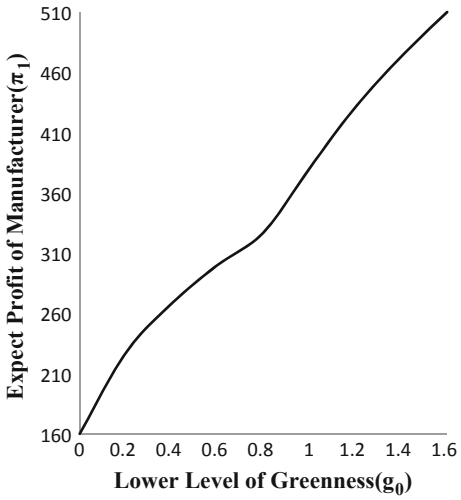

Fig. 91.3 Effect of the variation of g_0 on π_1

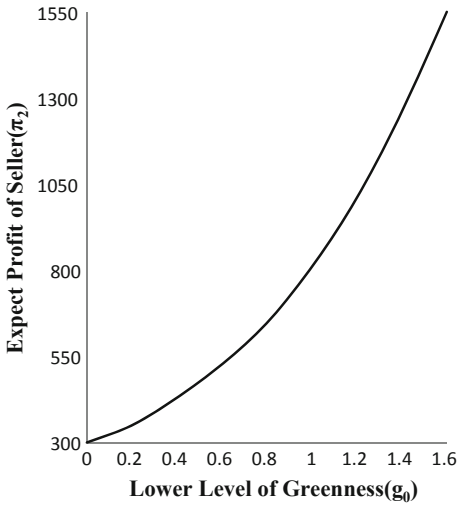

Fig. 91.4 Effect of the variation of g_0 on π_2

trend: the product's greenness level g_m, manufacturer's unit wholesale price w, manufacturer's expected profit π_1, seller's expected profit π_2. From Figs. 91.1, 91.2, 91.3 and 91.4, we can found that with the increasing of g_0, the product's greenness level g_m showed a gradual upward trend, the wholesale price w shows a trend from rise to decline, the expected profit of manufacturer and the retailer are all increased. Increased lower limit of greenness means the improving of subsidies access threshold, which will enable manufacturers to carry out more research and development innovation activities, enhance the greenness of products and gain more profits; on the other hand, increased lower limit of greenness can narrow the scope of government subsidies, so the unit product will receive more subsidies in the case of a certain

amount of state financial subsidies, so the sale price of green products is lower and consumer demand is increased, which will increase seller's order quality. Therefore, in order to reduce the adverse effects of uncertain market demand on the supply chain members, the government can set a higher access threshold for subsidies, such as the policy of energy subsidies released in 2010, which stipulates to give subsidies to air conditioning which energy-saving level is above 1.

91.6 Conclusion

In his paper, we conduct a comprehensive consideration of various factors such as government subsidies, product's greenness and consumer demand uncertainty, then build a three-stage game model containing manufacturer, retailer and customer, and finally analyze the impact of demand uncertainty on the decision-making of supply chain members and the incentive mechanism of government participation. The results show that through increasing subsidies level and access threshold, the green supply chain members are willing to improve products' greenness level and order quantity, which is conducive to achieving social environmental goals. In order to better play the role of government participation in green supply chain management and achieve all-win, this paper put forward the following two recommendations:

(1) Firstly, the government should develop relevant policies, grasp the market information and promote green products in the whole society, the government should give a certain degree of subsidies to consumers who purchased products with a higher greenness level, improve people's environmental awareness, and set reasonable subsidy policy in fiscal, taxation, credit and other aspects, give biggest support to those companies who are willing to carry out green supply chain management. In the early stage of the green product consumption market, the government can set a lower threshold and a larger adjustment factors, so as to achieve the purpose of promoting industrial upgrading; when the green product market gradually mature, the task of optimizing industrial structure will shift from government-oriented to enterprise-dominant type, at that time the government need to gradually increase the lower subsidies limit, reduce the adjustment factor and finally withdraw the subsidy policy. At the same time, the government should implement strict environmental protection policy, increase the supervision, and force enterprises and consumers to carry out green supply chain management through coercive measures.

(2) Manufacturers need to realize that the government subsidy is a short-term behavior aiming to promote industrial transformation, under such tendency; manufacturers should continue to improve technical capabilities, develop better green products, enhance the core competitiveness of enterprises, and develop a long-term virtuous cycle so as to achieve the original intention of the government subsidy policy. At the same time, manufacturers should take efforts to control the risk of output fluctuations in the production process, which can achieve the greatest benefits in the changing market demand.

Obviously, there also exists some insufficient places, for example, the paper hasn't considered different levels of greenness may correspond to different product prices, and consumers may not be neutral preference to different greenness products, different levels of greenness will lead to different demand response. Also, this paper only takes single manufacturer and seller into account, so the further research can consider more members, which also can increase the game's possibility. This paper only analyzes the situation of the supply chain downstream, in fact, upstream of the supply chain can also be analyzed, such as the uncertainty of raw materials' supplement and so on. At the same time, manufacturers can consider not only the profit problem, but also the revenue stability as well as the stock out influence. These issues will become the research direction of the next step in the research of the green supply chain under the condition of the government subsidies.

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