EMISSIONS TRADING

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ABSTRACT

Emission trading is a system of or rights or permits that give the holder the right to emit one unit of designated pollutant. Permits or rights to pollute can then be considered an input to production and are priced like any other commodity. The idea behind emissions trading is to meet environmental goals the lowest possible cost when compared to other environmental policies such as command-and-control or emissions taxes. Simple in concept, emissions trading can become complex in practice when considering all elements that must be in place. The most widely used trading mechanism is cap-and-trade where the overall emissions level is capped, and permits can be traded between emissions sources. Other forms of trading, though not used as often as cap-and-trade, include offset or project trading and emission rate trading. Early experience with emissions trading with offset or project-based trading, as well as the current experience with cap-and-trade, have resulted in significant cost savings to participants versus traditional command-and-control methods, but have not achieved all the possible cost savings available.

KEYWORDS

Emissions Trading, Cap-and-Trade, Emissions Reduction Credits, Offset Trading, Least-cost Emissions Compliance

INTRODUCTION: IDEAS AND CONTEXT BEHIND EMISSIONS TRADING

The idea of **emissions trading**, popularized by [1] and then formalized by [2] is to create a system of property rights or permits, or as they are called in many trading programs, allowances, in the spirit of [3] that would give the holders of the rights/permits the right to emit one unit of pollutant. These rights/permits/allowances can be thought of as inputs to production much like any other input such as coal, oil, or natural gas, and thus would have a market determined price and be tradable like any other commodity, and these right have value because the number of rights available is limited (capped) either explicitly or implicitly. As shown by [2] and reproduced in [4], **emissions trading** has the property of meeting an aggregate emissions (reduction) target at the lowest possible cost because trading provides the ultimate flexibility to polluting sources in how best to meet the emissions target. Not only do sources have the flexibility in choosing technologies or input mixes to minimize the cost of meeting emission targets at individual sources, but sources can buy and sell the permits/rights/allowances to pollute among each other to allocate the burden of emissions reductions in such a way as minimize the cost in aggregate across all sources. A cost minimizing allocation of emissions reductions results in sources with low costs of abatement making greater reductions and those with higher costs of abatement making fewer reductions than they may otherwise make under command-and-control (CAC) policies, and thus it can be said that the cost saving benefits of emission trading *vis-à-vis* CAC policies is greater the greater is the variability in emissions control costs.

As a policy option to achieve environmental compliance with pollution reduction goals **emissions trading** is relatively new in its widespread application, though the first trading programs go back to the mid 1970s and have been used in a variety of contexts [5]. Prior to the launching of the first emissions trading schemes, the policy option to meet environmental objectives came in the form of command-and-control (CAC) regulations where emissions sources either had to meet a legislated emissions rate standards or to meet a stated technology standard. On a larger scale, the early policy for air pollution in the United States, beginning in 1970, mandated specified concentration levels of pollutants had to be attained an then maintained at or below those levels going forward under the National Ambient Air Quality Standards (NAAQS). Many areas were in non-attaintment of the standards which would not permit the entry of new emission sources that would be associated with economic growth [6]. Consequently, the first emissions trading scheme, an offset policy or emission reduction credit (ERC) trading mechanism was born out of the necessity to accommodate economic growth while still moving toward attainment of the NAAQS in the middle 1970's [7]. The system was quite simple in concept. Existing sources in an area could reduce their emissions below an administratively defined baseline level, and could then sell those offsets or ERCs to a new source entering the area at a price agreed upon by the parties. A variant of offset trading known as a bubble was introduced in 1979. The bubble provided flexibility to allocate emissions among multiple sources at the same facility (e.g. multiple generating units at the same plant) so long as total facility emission did not exceed a specified level [8].

The movement to **emissions trading** as a policy option has also been driven by the cost of CAC policies relative to the least-cost way of meeting emissions standards. As shown in [6], there were a multitude of studies conducted during the 1980's showing ratios of CAC cost to least cost in a range from as low as 1.07 to as high as 22. The movement toward widespread application and acceptance of cap-and-trade programs led by the Title IV Sulfur Dioxide (SO_2) Trading Program (SO_2 Program) from the 1990 Clean Air Act Amendments (CAAA) can be seen as the meeting of environmental interests who wish to see further emissions reductions with business and political interests who wish to see market-driven policies [9].

TYPES OF TRADING MECHANISMS

Cap-and-Trade

Under a cap-and-trade scheme, the aggregate level of emissions is capped, and property rights/permits/allowances are created such that the number of allowances available does not exceed the cap. Examples of cap-and-trade markets include the markets facilitated by the United States Environmental Protection Agency (USEPA) including the current SO_2 Program and NO_x SIP Call Program, and the soon to be implemented Clean Air Interstate Rule (CAIR) and Clean Air Mercury Rule trading programs [10], the Regional Clean Air Incentives Market (RECLAIM) in California [11], and the European Union’s Emissions Trading Scheme (EU ETS) [12]. Cap-and-trade programs are perhaps the most used and visible of all emissions trading programs.

Offset or Project-Based Trading

In an offset or project-based trading scheme, similar to that described above, potential emissions sources create credits by reducing emission below their administratively determined baseline, so that credits can be sold to other sources that may be emitting more than their baseline. The emissions reduction credit (ERC) generated in this scheme is generally not a “uniform commodity” like the permit/property right/allowance that is defined under a cap-and-trade regime, but is the number of ERCs created or needed is often determined on a project (case-by-case) basis. The spirit of an offset scheme is to implicitly cap emissions, though this is likely not the case in practice [8]. In depth descriptions of such programs for the US can be found in [13] and [14]. An example in the context of carbon policy is the Clean Development Mechanism [15].

Emissions Rate-Based Trading

In a rate-based trading environment an emissions rate standard (e.g. lbs/mmBtu) is determined that must be met in aggregate, but sources can create credits that are created by reducing emissions rates below the standard and sell these to sources with emissions rates above the standard. An example of this type of trading program exists for electric utility nitrogen oxide (NO_x) sources subject to Title IV of the 1990 Clean Air Act Amendments (CAAA) [16]. Under this program sources within the same company may trade credits to meet the NO_x emissions rate standard. Because credits are being traded to meet the standard, emission are in general not capped [8].

ELEMENTS OF EMISSIONS TRADING PROGRAMS

As cap-and-trade emissions trading programs are the most prevalent, active, and visible, most of the elements in trading regimes are described with cap-and-trade in mind, though many of these elements also relate to other forms of trading in many cases. The format of this section closely follows [8].

Definition of Affected Sources

Determination of the emission sources to be included in the program (affected sources) is essential. Ideally, as many emissions sources as possible should be included in any trading program, but there also must considerations given with respect to the size of the source, ability to monitor and report emissions from the source, and any other considerations that may be deemed as important. For example, under the SO_2 Program existing simple cycle combustion turbines and steam units less than 25 MW in capacity were exempt from the program. One could surmise that such technologies were not large sources of SO_2 emissions or were too small to monitor in a cost-effective manner.

Measurement, Verification, and Emissions Inventory

Without the ability to measure emissions, emissions trading programs would not be workable. The measurement of emissions for the inventory can either be done through a monitoring system, or can be done through the use of mass-balance equations. In order to verify emission monitoring results can be checked against mass-balance equation derived emissions readings to ensure robust readings. The measurement of emissions prior to the commencement of a trading program can help provide a basis by which to set a cap and allocate permits/allowances in a cap-and-trade system, to set a baseline by which the emissions reductions can be measured in an offset systems, or determine emission rates.

Determination of an Emissions Cap

In cap-and-trade systems, the element that makes emissions reductions valuable is the program-wide limit on total emissions. The decision on the level of the emissions cap is as much political as it is scientific. In an ideal world with perfect information, the cap would be set so that the net benefits to society would be maximized (marginal costs of emissions reductions would equal the marginal benefits of reduction). However, determining benefits is not as easy as determining costs of pollution reduction, though great strides have been made in recent years. As a matter of practice, while consideration is given to maximizing net benefits to society, the level of the cap is often determined through political means to gain wider stakeholder acceptance [9].

Unit of Trade: Allowance/Permit/Emissions Reduction Credit

In order to facilitate trading among sources, it is crucial to define the unit of trade between emissions sources. In the academic literature these are sometimes called permits. In the language of the US EPA, they are known as allowances in cap-and-trade systems, and as emissions reduction credits (ERC) in offset and bubble systems in the US. Regardless of the nomenclature a permit/allowance/ERC gives the holder the right to emit one unit of pollutant where units can be defined in pounds, tons, kilograms, or any other accepted unit of measure. In effect, the allowance/permit/ERC is a property right to pollute and can be traded between sources at a price amenable to the parties as any other commodity could be.

Compliance Period and True-Up

The time period for which emissions are to be controlled must be defined. For emissions in the SO_2 Trading Program, the compliance period is January 1 to December 31, while in the NO_x OTC Market it was May 1 to September 31 [16]. Sources must have allowances at least equal to their emissions during the compliance period. A trading regime may also allow a true-up period during which sources may verify their actual emissions during the compliance period and then buy or sell allowances for the purposes of meeting the just concluded compliance period obligations.

Allowance/Permit Allocation or ERC Baseline

Under cap-and-trade permits/allowances must be allocated to affected sources, or in the case of an offset system, the baseline must be established by which reductions are measured and ERCs are created.

With respect to cap-and-trade, there are three primary allocation methods: historical baseline, fixed; auction; and historical baseline with updating. Allocations may also be created for new units, or as a reward for undertaking certain actions to reduce emissions quickly or by other means. Under historical baseline, fixed methods, the allocation is *gratis* and is determined by a measure of performance for affected sources from the past. The performance measure could be based on output or input. Being based on the past, affected sources cannot engage in any behavior in an attempt to gain larger allowance allocations. For example, for Phase I units in the SO_2 Program announced in 1990, allocations were based on an emissions rate per unit of heat input from 1985-1987.

Under an auction allocation method, the allowances are sold directly to sources at a pre-determined interval in advance of the time affected sources will need the allowances to cover their emissions.

Under an updating methodology, allowance allocations beyond the first years of the program are determined based upon updated performance measures such as heat input or output rather than permanently fixing allocations to the historic performance. For example, some countries in the EU ETS have decided to use an updating allocation method in which sources that are shut down permanently will have their allocations taken away [17].

Choosing a baseline is crucial for offset programs as the baseline determines how many ERCs are created through abatement. The determination of what the baseline might be varies across jurisdictions and is often open to negotiation in US-based programs [14].

Spatial and Temporal Trading Rules

The wider are trading opportunities across space and time, the greater is the potential for cost savings from trading. Still, there may be political or environmental considerations that may necessitate rules defining and restricting how trade can be made across space and time. For example, if the pollutant being traded is seen to create greater damages where it is concentrated (such as mercury) or may become highly concentrated due to wind and weather patterns (NO_x and SO_2), then it may be necessary to create spatial trading ratios that differ from a one-to-one exchange, or restrict trades from one zone to another as has been done in the RECLAIM program [18].

The ability to create ERCs or to save allowances for future use is known as banking. Banking ERCs or allowances is a way of trading between time periods and is allowed in many programs. Such a practice is warranted if concentration increases at a point in time are not troublesome, but if increased pollutant concentrations at a point in time such as NO_x during summer ozone season, banking may not be allowed such as in RECLAIM or by some states in the NO_x SIP Call Program [18].

Penalties and Enforcement

All affected sources in a trading program must enough allowances to cover its emissions in a cap-and-trade program. Without penalties or enforcement, there is no reason for sources to buy the necessary allowances to be in compliance. In cap-and-trade systems, a penalty per allowance not held, well in excess of the market price of allowances, for any shortfalls in allowances is necessary so that sources will participate in the market and maintain the emissions cap and not simply opt out by paying no, or a small, penalty.

FIRM INCENTIVES UNDER EMISSIONS TRADING

Consider a cap-and-trade system where allowances have been allocated already, but keep in mind that the same logic applies to offset and emission rate trading systems. If a generating unit has low abatement costs, that unit can reduce emissions below its allowance allocation and sell the remaining allowances or simply bank them for future use. For example, as long as the marginal (incremental) cost of abatement (emissions reduction) is less than the allowance price, it pays the generating unit to further reduce emissions and sell the freed-up allowance. This can be seen in Figure 1 below.

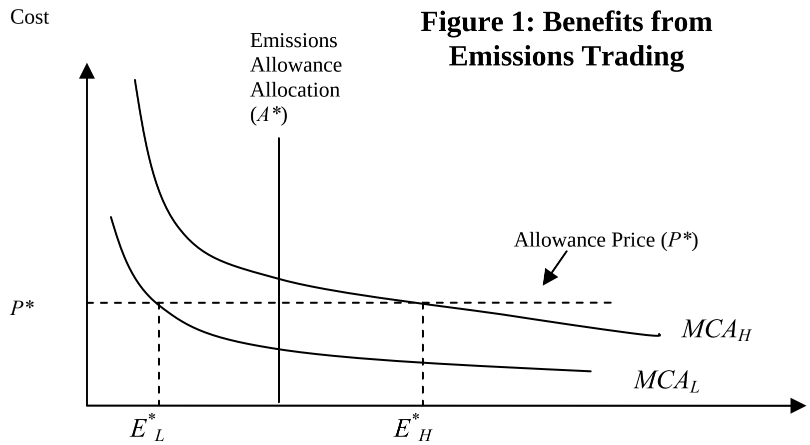

Figure 1: Benefits from Emissions Trading

MCA_L represents a low marginal abatement cost source. Being allocated $A*$ allowances, if the market price of allowances is $P*$, it pays a generating unit that has low abatement costs to reduce emissions until it reaches E^*_L. The revenue from allowance sales is the rectangle with the width $A* - E^*_L$ and height $P*$. The cost to the utility company is the area under MCA_L between $A*$ and E^*_L. The net profit from the allowance sale is the area of the revenue rectangle above MCA_L. Conversely, a unit may have high abatement costs, represented by MCA_H. Rather than reduce pollution, that unit may find it less expensive to buy allowances in the open market, and use the purchased allowances, along with the allowance allocation, to cover its emissions obligation. Units will continue buying allowances as long as the marginal (incremental) cost of abatement (emissions reduction) is greater than the allowance price. A more formal way of expressing this idea is that the unit with high abatement costs (Figure 1) will buy $E^*_H – A*$ allowances in the market at the price $P*$. That unit’s expenditure on allowances is the rectangle with width $E^*_H – A*$ and height $P*$. Because its reduction in abatement costs, the area between $A*$

and E^*_H and below MCA_H, is greater than the expenditure on allowances, the unit with high abatement costs will benefit. Also note that the allowance market leads to the equalization of the marginal costs of abatement across generating units.

COST MINIMIZING POLLUTION ABATEMENT WITH EMISSIONS TRADING

Consider the following example with two firms with the objective of minimizing the cost of achieving the aggregate emissions restriction of 2000 tons in Table 1. Let E_i in Table 1 represent the unrestricted or baseline emissions level for firm i. Let e_i be the emissions level of firm i after abatement, so that abatement for firm i is equal to $(E_i - e_i)$.

Table 1: Two Firm Cost Minimizing Example

	Firm 1	**Firm 2**
Unrestricted/Baseline Emissions (tons) E_i	2000	2400
Total Cost of Abatement Function	$C_1(E_1 - e_1) = 0.5(E_1 - e_1)^2$	$C_2(E_2 - e_2) = 0.1(E_2 - e_2)^2$
Marginal Cost of Abatement Function	$MCA_1 = (E_1 - e_1)$	$MCA_2 = 0.2(E_2 - e_2)$
Aggregate Emission Restriction	$e_1 + e_2 \leq 2000$	

The least-cost solution for emissions abatement can be solved by minimizing the cost of abatement subject to the aggregate emissions restriction:

$$\text{Min}_{e1,e2} \; C_1(E_1 - e_1) + C_2(E_2 - e_2)$$
$$\text{s.t. } e_1 + e_2 \leq A^*$$

The solution to this problem requires the marginal cost of abatement (MCA) be equalized across the firms as shown in the solution to this problem in Table 2. Also note in Table 2 that Firm 2 makes much larger reductions (2000 vs. 400) than Firm 1 as its cost of abatement is only a fifth of that for Firm 1.

Table 2: Least-Cost Solution to the Two Firm Example

	Firm 1	**Firm 2**
Emissions Level, e_i	1600	400
Abatement Level, $(E_i - e_i)$	400	2000
Total Cost of Abatement	80,000	400,000
Marginal Cost of Abatement	400	400
Aggregate Abatement Cost	480,000	

Now consider a cap-and-trade emissions trading program. Let X_i be the allowance allocation for firm i and x_i be the allowance purchase ($x_i > 0$) or allowance sales ($x_i < 0$) position of firm i. Let P be the price of allowances in the market. Each firm in the market minimizes its cost of pollution abatement and allowance purchases/sales subject to the restriction that emissions, e_i, are less than or equal to the allowance allocation plus the net position:

$$\text{Min}_{\text{ei,xi}} \; C_i(E_i - e_i) + Px_i$$
$$\text{s.t. } e_i \leq X_i + x_i$$

The solution to this problem for each firm requires its MCA be equal to the allowance price P just as shown in Figure 1, where the allowance price is the mechanism by which marginal costs of abatement are equalized across firms. Additionally, the aggregate emissions constraint must be satisfied $\Sigma_i \, e_i \leq \Sigma_i \, X_i$, and assuming no banking, the sum of allowance sales and purchases are equal to zero $\Sigma_i \, x_i = 0$.

Extending the example in Table 1 assume that each firm is initially allocated 1000 allowances signifying the right to emit 1000 tons. We know each firm reduces emissions up to the point where MCA=P, and the MCAs are equal across firms. Consequently, we arrive at the same emissions outcome and MCA as the least-cost solution in Table 2. This results in Firm 2 having 600 surplus allowances which it sells to Firm 1 which needs 600 allowances at a price of 400/ton (MCA). The results of this can be seen in Table 3.

Table 3: Solution to the Emission Trading, Two Firm Example

	Firm 1	**Firm 2**
Allowance Allocation, X_i	1000	1000
Emissions Level, e_i	1600	400
Abatement Level, $(E_i - e_i)$	400	2000
Allowance Position, x_i	600	-600
Total Cost of Abatement	80,000	400,000
Marginal Cost of Abatement	400	400
Allowance Price	400	
Allowance Costs	240,000	-240,000
Aggregate Abatement Cost	480,000	

It is important to note that the allowance purchases and sales cancel each other out in aggregate and the actual abatement cost is the same as the least-solution found in Table 2.

An important lesson from the results in Table 3 is emissions trading can achieve the least-cost solution without the need for collecting detailed information on sources' abatement costs, and as we will see below, the method by which allowances are allocated does not change this result.

Allowance Allocation and Distribution of Costs

How allowances are allocated across firms, whether allocated *gratis* or by auction, the distribution of the initial allocation, once determined, does not change the aggregate abatement cost, although updating methods introduce other inefficiencies and effects as discussed in [17] and [19]. However, shifting allocations does change the distribution of the cost burden to meet the aggregate emissions constraint. In the previous example, we assumed each firm was allocated 1000 allowances. Suppose instead that Firm 1 is allocated all 2000 allowances and Firm 2 gets none. This does not change the optimizing behavior on how much is emitted, nor does it change the aggregate abatement cost. What is does do it change the allowance position of each of the firms: Firm 1 sells 400 tons giving it allowance revenues of 160,000 and Firm 2 buys 400 tons adding 160,000 in allowance costs. The allowance price, *P*, remains unchanged at 400. All that has changed is the distribution of the cost burden in meeting the aggregate emissions constraint.

Suppose instead of a *gratis* allocation of allowances, the allowances were auctioned off and the revenue kept by the government for use elsewhere such as offsetting other taxes. In this case, the allocations X_1 and X_2 are equal to zero and the net allowance position for each firm is equal to the number of allowances they would need to satisfy their emissions constraints. Once again, the change in allocation method does not change the optimizing behavior of firms as seen in Table 3 as they still produce the same emissions (e_1=1600, e_2=400), nor does it change the allowance price, which is still P=400. What does change is the allowance cost for the firms. Under the *gratis* allocation, some firms were, in effect, allocated revenues from allowance sales or costs associated with allowance purchases for the difference between their allowance allocation and optimal emissions decision and effectively, need not pay anything for their emissions that are covered by the initial allocation. Under an auction, firms pay the government directly for their emissions through the purchase of allowances at auction. Given the optimal emissions levels and the allowance price, Firm 1 would pay 640,000 in allowance costs at auction and Firm 2 would pay 160,000 in allowance costs providing 800,000 in auction proceeds to the government which were forgone with the *gratis* allocation scheme.

Emissions Trading Vs. Command-and-Control (CAC)

Suppose instead of emissions trading, the environmental regulator promulgated a CAC regime where each firm had to reduce its emissions by 1200 tons each, and equal share of the reductions needed to get emissions down to 2000 tons. Such a regime leads to certainty regarding the emissions level, but mandating each firm to reduce by the same amount (in total quantity or percentage terms) is quite unlikely to lead to the least-cost solution. The results of the above CAC scheme can be seen in Table 4 below.

Table 4: Command-and-Control Costs

	Firm 1	**Firm 2**
Required Reductions $(E_i - e_i)$	1200	1200
Emissions Level, e_i	800	1200
Total Cost of Abatement	720,000	144,000
Marginal Cost of Abatement	1200	240
Aggregate Abatement Cost	864,000	

The aggregate abatement cost under this CAC regime is almost double the cost from emissions trading (864,000 vs. 480,000). The MCAs are not equalized under CAC and the MCAs indicate Firm 2 should engage in more abatement and Firm 1 should engage in less abatement activity in an effort to equalize the marginal costs across firms.

The only way in which the CAC regime could achieve the least-cost solution is to collect detailed information on the costs of abatement at the firm or source level so as to implement the least-cost outcome as the CAC targets.

Emissions Trading Vs. Emissions Taxes

Rather than using command and control or emissions trading to reduce emissions, the environmental authority wishes to employ emissions taxes to reduce emissions. The incentives under emissions taxes are similar to those under emission trading as shown in Figure 1. Firms will wish to reduce emissions until the marginal cost of abatement is equal to the tax rather than the allowance price. The difference between the two regimes involves the certainty with which an emissions target will be met. Under emissions trading, there is certainty about the emissions resulting from the program, assuming no banking, but the allowance price is uncertain as it is endogenously determined. With emissions taxes, the price of emissions is certain, but resulting emission level is endogenously determined.

Suppose the environmental regulator imposes an emission tax of 300 per ton. By design, the marginal costs of abatement are equalized across firms, thus minimizing the cost of meeting the uncertain emissions level. Table 5 shows the result for the tax of 300 per ton.

Table 5: Emissions Tax of 300/Ton Results

	Firm 1	**Firm 2**
Emissions Level, e_i	1700	900
Reductions $(E_i – e_i)$	300	1500
Total Cost of Abatement	45,000	81,000
Marginal Cost of Abatement	300	300
Aggregate Emissions	2600	
Aggregate Abatement Cost	126,000	

The resulting emissions of 2600 are greater than the target set forth under either emission trading or command-and-control, although this higher emissions level is achieved at least-cost. If the goal is to achieve the 2000 ton limit with emissions taxes, this would require a constant adjustment of the tax level until the goal is met. However, such adjustments to the tax would introduce uncertainty and increase risk for firms operating in their respective industries and would likely be fought by the owners of the affected sources.

EXPERIENCE WITH EMISSIONS TRADING PROGRAMS AND CONCLUDING THOUGHTS

The early experiences with offset trading programs was that there were cost savings achieved by these programs but there were many opportunities for cost savings that went unexploited due to administrative complexity and burden and the environmental improvements were not as great as was hoped [7], [13]. More recent programs have seen little trading as other environmental programs have resulted in greater reductions reducing the demand from credits [14].

[18] provide a survey of performance of US cap-and-trade programs while [9] offers a comprehensive analysis of the early years of the SO_2 Program and [16] offers insight into federal NO_x trading programs. Overall, there is general agreement that the cap-and-trade programs in the US have offered significant cost savings, technological innovation, and have resulted in significant emissions reductions. Moreover, no emissions “hot spots” or locally high concentrations have been found as were feared by environmentalists. Still, there is a growing consensus that the existing programs have not achieved all of the possible cost savings from trading with one possible explanation being affected sources facing economic regulation by state commissions as discussed in [20].

The RECLAIM market suffered a severe setback as a result of the California electricity crisis and poor design such as not allowing banking.

The EU ETS is only 18 months into operation at the time of this article and little can be said about its performance or the performance of the CDM to date. Still, the movement of the EU towards emissions trading, based on the US experience, shows confidence in emissions trading and that the experience to date has been more positive than negative and has delivered reduced emissions at lower cost than traditional CAC regimes.

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