Achieving environmental goals at minimium cost

erm: rough draft, February, 29, 2011

Efficiency dictates that if society want to produce X units of a commodity, those units must be produced in the minimum-cost way from **society's** perspective.[1]

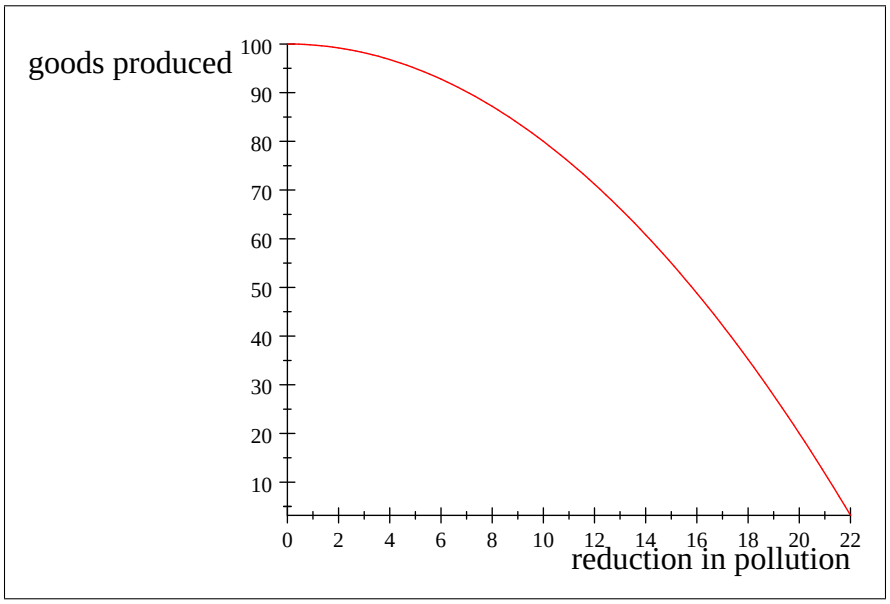
If the costs of production are not minimized, it would be possible to produce the X units using fewer of society's resources. If this is possible, things cannot be efficient: the resources that could be saved could be used to improve society in some other way: if society wastes resources in production, things are inefficient.

This is true of all producing, including the production of reduced pollution (pollution abatement).

It is also true of cleaning the toliet, you want to minimize the cost of the time and resources used to clean the toliet, unless, of course, you are really into toliet cleaning.[2]

Consider a *production-possbilibites frontier*, a PPF, with goods on one axis and pollution reduction/abatement on the other.

Assume the tradeoff looks as follows:



[1] To maximize profits the firm want to produce its chosen level of output at minimum cost from the firm's perspective. But, private costs of production might be different from the social costs of production. That is, production might impose costs on society that the producer does not have to pay.

[2] I made the mistake of googling "toilet cleaning fetish."

Production possibilities frontier: goods vs. pollution reduction.

So, if the world is like this, we could have 100 units of goods, and all of the pollution associated with the production of the 100 units. But, as we allocate more and more resources to cleaning up (abating) pollution, there are fewer resource available to produce goods, the quantity of goods produced declines.

Al Gore (the guy who sort of beat George Bush in a Presidental election) is technically wrong when he says we can have both more goods and a cleaner environoment (He could be correct if current production is highly inefficient.)

Efficiency dictates that society operates on this production frontier, not inside of it.

If society reduces pollution by 10% but does not achieve that reduction in the minimum cost way, we are inside the PPF.

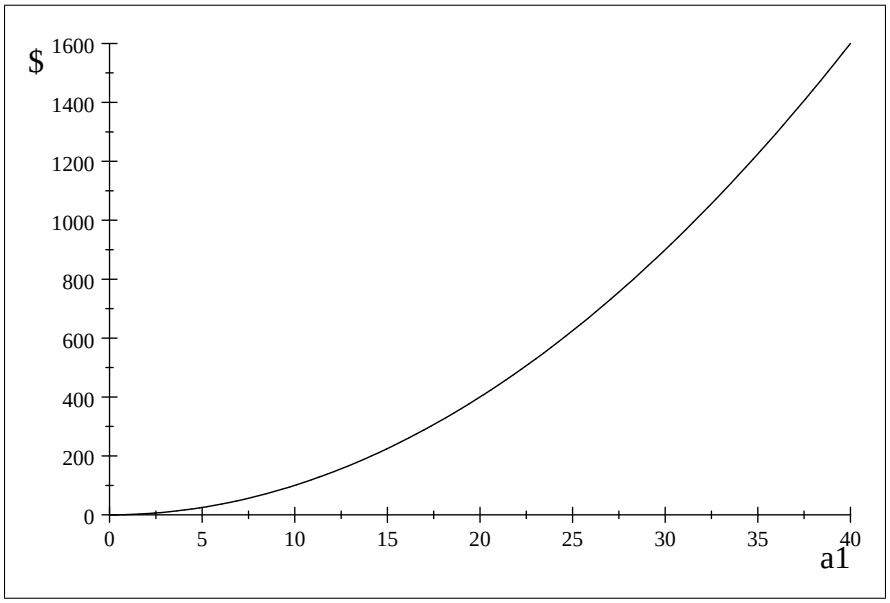
Consider the following problem

1 Three firms pollute guber gas into the environment, and the government wants the total amount of guber gas emitted reduced by X units.[3]

1.1 Assume unregulated Firm 1 is currently producing 40 units of pollution (guber gas) and its marginal cost curve for reducing pollution is

$MC_1(a_1) = a_1^2$ where a_1 is the number of units of pollution abated by Firm 1,

so $TC_1(a_1) = (1/3)a_1^3$



Firm 1: marginal cost of abating gg pollution

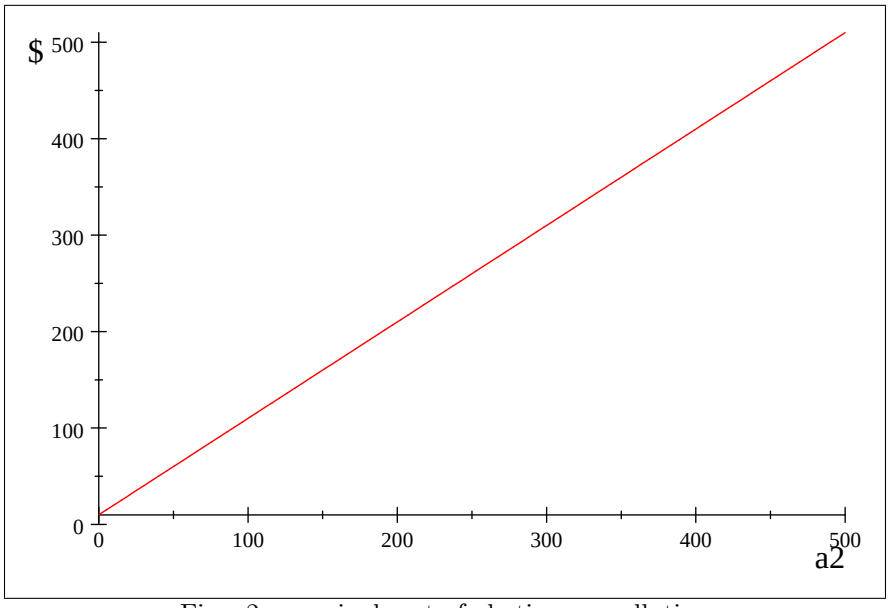
[3] Guber gas smells bad and makes everyone look ugly.

It inexpensive to abate the first unit of guber gas, but the more you abate the higher the marginal cost of abatement.[4]

1.2 Firm 2 is currently producing 500 units of gg pollution and its marginal cost curve for reducing pollution is

1.3

$MC_2(a) = 10 + a_2$ where a_2 is the number of units pollution abated by Firm 2, so $TC_2(a) = 10a_2 + (1/2)a_2^2$



Firm 2: marginal cost of abating gg pollution

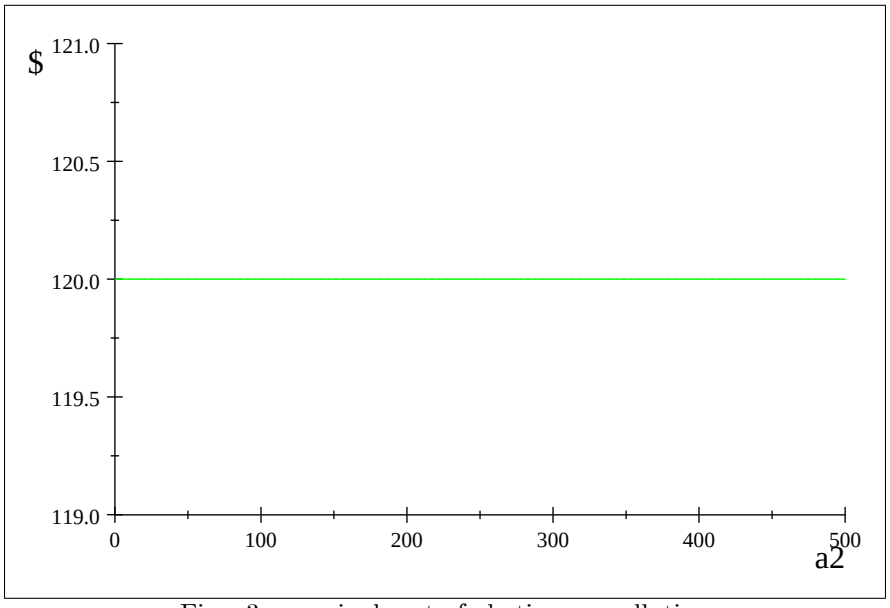
It costs Firm 2 \$11 $(10+1)$ to reduce pollution by one unit, and the the cost of each additional unit increases by \$1. For example, abating the fifth unit of pollution cost \$15 and abating the sixth unit costs \$16

[4] Not that this marginal cost of abatement curve is the KW "marginal social benefit: curve flipped over. Here abatement increases (pollution reduced) as one moves left to right. In the KW curve abatement increases as one moves right to left.

1.4 Firm 3 is currently producing 100 units of gg pollution and its marginal cost curve for reducing pollution is a constant $120.

1.5

$MC_3(a_3) = 120$ where a_3 is the number of units pollution abated by Firm 3, so $TC_3(a_3) = 120a_3$

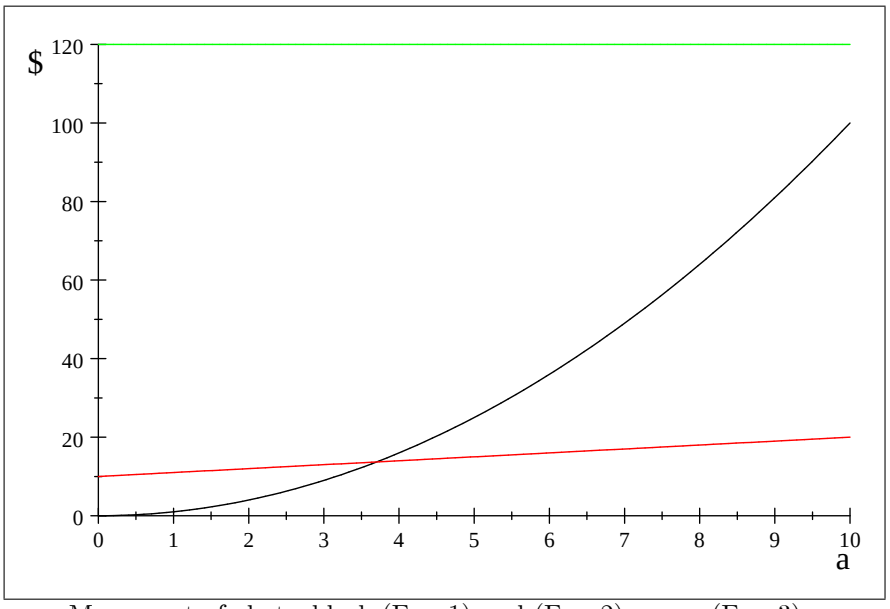


Firm 3: marginal cost of abating gg pollution

1.6 What is the minimun cost way to reduce pollution by 1 unit from its current level?

The answer is Firm 1 should do it: it would cost Firm 3 \$120 to reduce its pollution by one unit, \$11 for Firm 2, and \$1 for Firm 1, so having Firm 1 do it is the minimum cost way to achieve a one unit reduction in guber gas output.

This is visually apparent if one puts all three marginal cost of pollution abatement curves on the the same graph



Marg. cost of abat.: black (Frm 1), red (Frm 2), green (Frm 3)

This demonstrates that that requiring each firm to reduce their pollution by the same amount is not efficient. That is, if each firm reduced their pollution by 1/3 unit the total cost of the one unit reduction in gg pollution would be much higher. Can you figure out what it would cost?[5]

Efficiency dictates that the reduction comes from where it is cheapest to get it. (Looking ahead this has incredible implications for reduction CO_2 emission.)

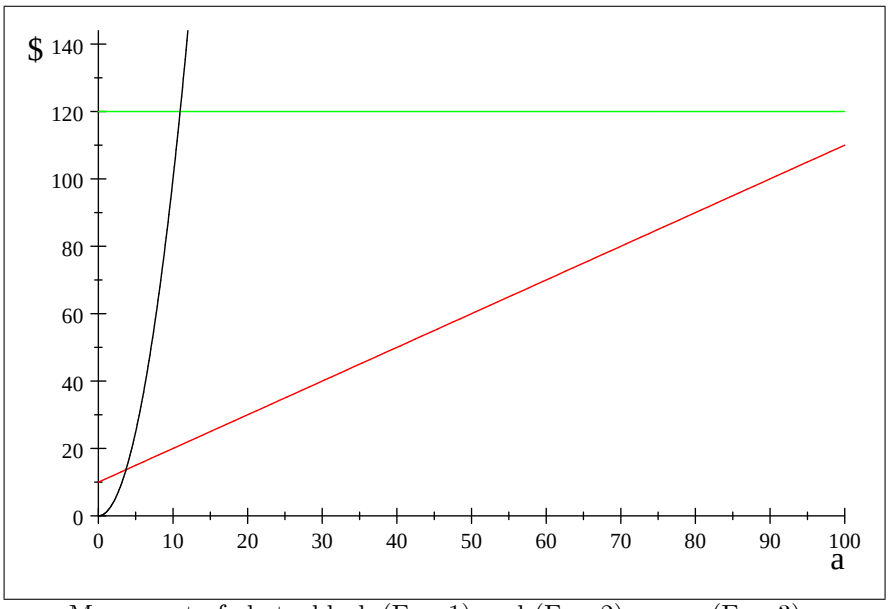
This a critical policy point: requiring all firms to reduce their pollution by the same amount is likely quite inefficient (not the least-costly way to achieve the goal).

[5] It would be $(1/3)^2 + (10 + 1/3) + 1/3(120) = 50.444$, fifty time higher than if firm 1 does it. Wow.

1.7 This is even clearer if the government want to reduce pollution by 100 units ($X = 100$)

1.8

Re-drawing the above graph on a different scale.

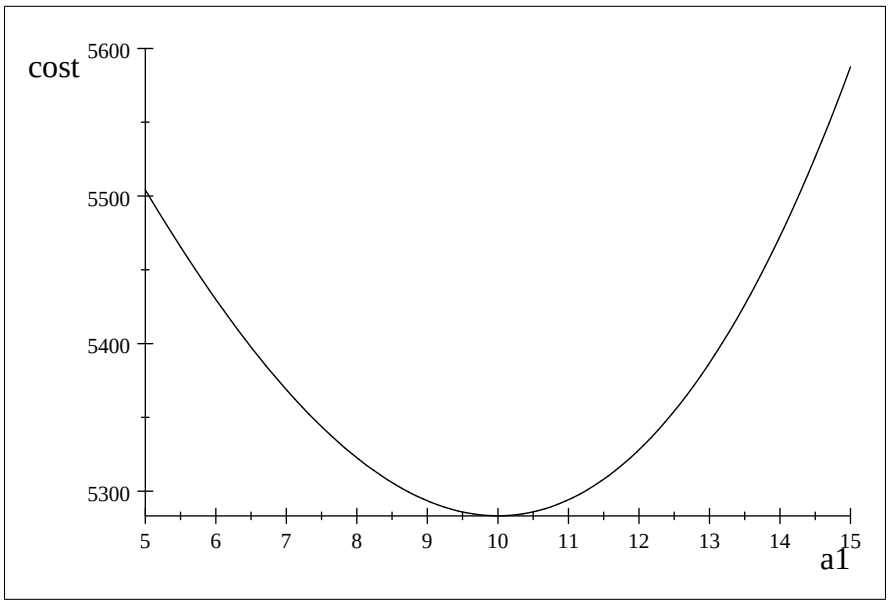


Marg. cost of abat.: black (Frm 1), red (Frm 2), green (Frm 3)

The first thing one sees from the graph is that if one want to reduce by 100 units of gg, at min. cost all of the reduction will come from Firms 1 and 2: Firm 3 should not reduce its pollution (because it is always cheaper for one of the other firms to abate one more unit).

This next graph shows how much of the reduction should come from Firm 1; it's 10 units, so 90 units from Firm 2[6]

[6] The equation for total cost of abating 100 units of pollution with Firm 1 abating a_1 units and Firm 2 abating $(100 - a_1)$ units is $(1/3)a_1^3 + 10(100 - a_1) + (1/2)(100 - a_1)^2$, the sume of the total cost function for the two firms.



Total cost of abating 100 units as a function of a_1

So, why is it that Firm 1 **should reduce by** 10 **units given that the marginal cost curves for Firms** 1 **and** 2 **cross around** 3**?**

The first unit of reduction from Firm 2 is \$11 so if one were only going to reduce pollution by 3 units, all of it should come from Firm 1 (the third unit of reduction for Firm 1 cost \$9, which is less than \$11, the cost of the first unit of reduction for Firm 1).

If we want to reduce a 4th unit, it is cheapest to have Firm 2 do it. (The fourth unit of overall reduction is the first unit of reduction for Firm 2 and it would cost Firm 2 \$11. Compare that to the fourth unit of reduction coming from Firm 1, which is $4^2 = \$16$.

The next four units of reduction should come from Firm 2 because the marginal cost for each of them is less than \$16. We have now reduced 8 total units.

The question is where should the next unit come from. It costs both firms \$16 to reduce one more unit (Firm 1 going from 3 to 4 units and Firm 2 going from 5 to 6 units). so we are indifferent to whether it comes from Firm 1 or Firm 2. But, if it comes from Firm 2 the next unit of reduction should come from Firm 1 (it costs Firm 1 \$16 to abate their fourth unit of guber gas and it costs Firm 2 \$17 to reduce their seveth unit of GG.

Then it is cheaper for Firm 2 until it has reduced a total of 15 units, then the next unit reduction is cheaper if it comes from Firm 1. Then it is cheaper

for Firm 2 until it has reduced a total of 26 units, then the next unit reduction is cheaper if it comes from Firm 1 (it is Firm $1's$ 6^{th} unit of reduction).

The following represent marginal cost of abatement for Firms 1 and 2 (I did fill in the whole table)

Walk through the table assuming for example a total reduction of GG of 30 units

unit	mc Firm 1	mc Firm 2	unit	mc Firm 1	mc Firm 2
1	1	11	26		36
2	4	12	27		37
3	9	13	28		38
4	16	14	29		39
5	25	15	30		40
6	36	16	31		41
7	49	17	32		42
8	84	18	33		43
9	81	19	34		44
10	100	20	35		45
11	121	21	36		46
12	144	22	37		47
13	167	23	38		48
14	$14^2 = 196.0$	24	39		49
15		25	40		50
16		26	41		51
17		27	42		52
18		28	43		53
19		29	44		54
20		30	45		55
21		31	46		56
22		32	47		57
23		33	48		58
24		34	49		59
25		35	50		60

10 units by Firm 1 and 90 units by Firm 2 is the cost-minimizing way to reduce overall pollution by 100 units.

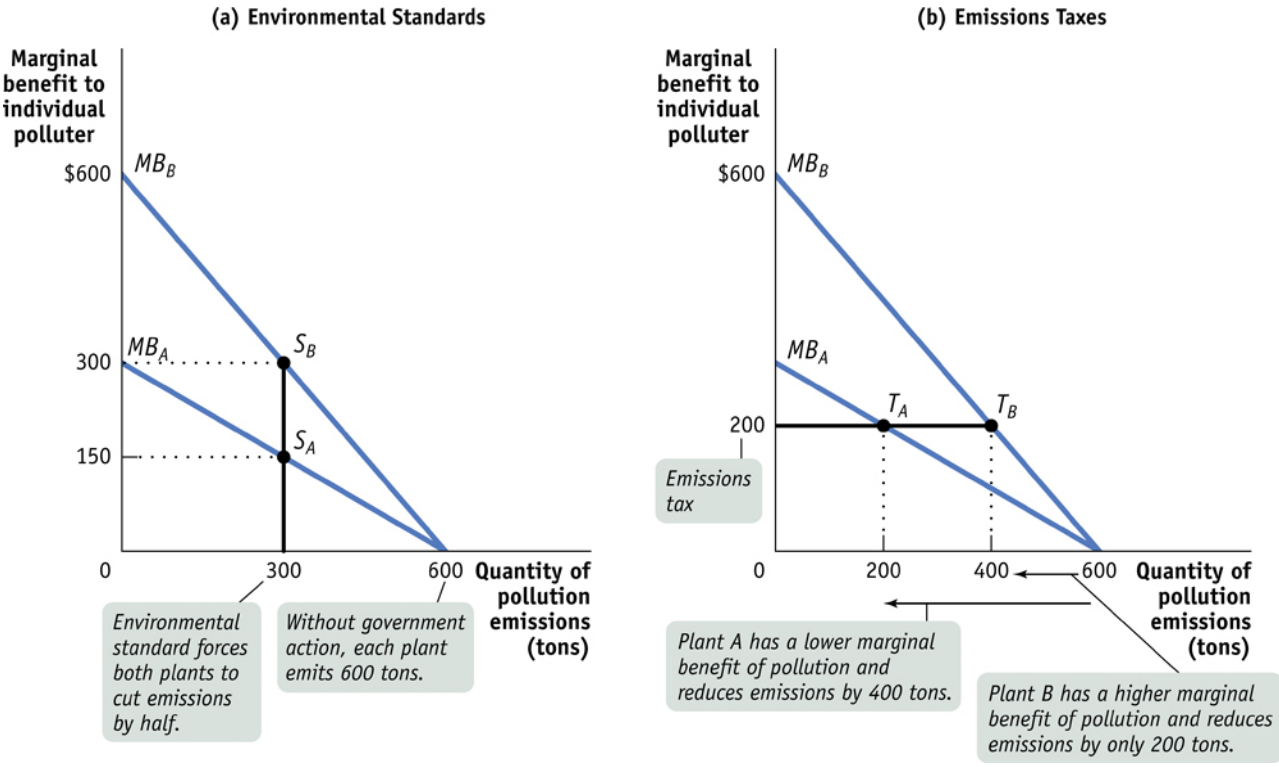
I did the math (integration) and it turns out that the total min. cost of abating the 100 units of Guber Gas is $\$5283.30$, if I did it correctly; it looks correct from the above total cost graph.

Alternatively, if the government required each of the three firms to reduce thei pollution by 33.3 units, the total cost would be $\$17,192$, more than three-times more.[7]

[7] $(1/3)(33.3)^3 + 10(33.3) + (1/2)(33.3)^2 + 120(33.3) = 17192.$

So having each polluter reduce their pollution by the same amount is not the efficient way to achieve the pollution reduciton goal. Studies show that requring all producers to reduce their pollution by the same amount is typically many times more expensive that the efficient way.

That said, historically the government has tended to reduce pollution with regulations that often require reach polluter to reduce by the same amount. This is stupid, a highly wasteful way to reduce pollution.



Note that having everyone reduce by the same amount will be cost minimizing if they are identical marginal cost of abatement curves.

1.8.1 Here is how KW represent a the case where the government want to reduce total pollution from 1200 tons to 600 total and does it with a regulation that requires each firm to reduce their pollution by 300 (the left graph)

There are two firms A and B. In their example, the marginal cost of abating curve for A lies below that of firm B. If both firms abated 300 units the marginal cost to society would be \$300 for B and \$150 for A - firm A is abatting too little and firm B too much

I find their graphs confusing.

Remember that the MB_x is (going right to left) is the cost to society of reducing pollution by another unit if firm x does it. (The resources firm x used to reduce the pollution could have been used to produce something else that would have benefited society.)

In the left pane it costs Firm B twice as much as it cost A to eliminated the 300^{th} unit of pollution.

The intent of the two graphs is two show that forcing each firm to reduce their pollution by 300 units is much more expensive than achieving the reduction with a pollution tax. In this case with the pollution tax, Firm A will reduce by 400 units and Firm B by 200.

2 How can we achieve the pollution reduction goal in the least-cost way?

Return to my three-firm example:

Remember that the government's goal is to reduce pollution from 640 units of Guber gas to 540 units of Guber gas (a 100 unit reduction, 19% reduction)

The goal is not achieved by requiring every firm to reduce their pollution by the same amount. (we want to get the reduction where it is cheapest to get)

Three ways it can be accomplished:

1. pass a law saying Firm 1 must reduce it pollution by 10 units (Firm 1 cannot emit more than 30 units of Guber gas), Firm 2 by 90 units (Firm 2 cannot emit more than 410 units of guber Gas), and Firm 3 is unrestricted.

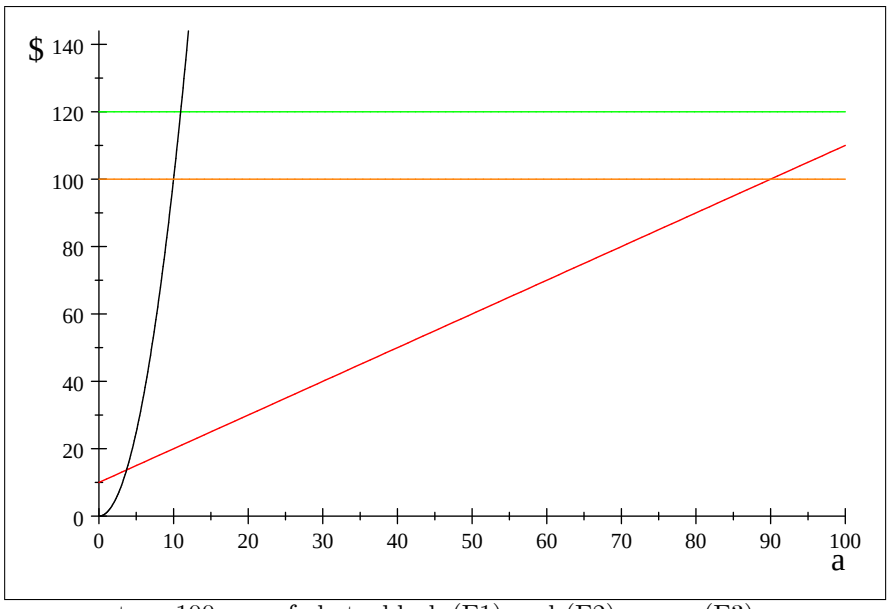
2. The government issues 540 pollution permits for Guber gas (one permit allows the holder to emit one unit of gas). The government gives the permits to the 3 emitters of Guber gas (maybe on the basis of how much they currently emit). If so, 33.75 to Firm 1, 421.88 to Firm 2, and 84.375 to Firm 3. The government closes down any Firm that emits Guber Gas that they do not have a permit to emit.

   The firms buy and sell permits amongst themselves until all the potential for Pareto-improving trades is exhausted. Specifically, Firm 1 will sell 3.75 permits (keeping 30), Firm 2 will sell 11.88 permits (keeping 410), and Firm 3 will buy them, so it ends of with a total of 100 permits (84.375+ $3.75 + 11.88$)

   As we see below, the equilibrium price of a permit will be \$100.

3. The government taxes the three firms \$100 for each unit of gg emitted.

   Returning to the graph of the marginal cost curves for the three firms, but adding the tax line at \$100 we see that Firm 1 reduces gg emissions by 10 units (saving a \$1000 in taxes), Firm 2 reduces by 90 units (saving \$9000 in taxes) and Firm 3 just pays the taxes.



tax=100, mc of abat.: black (F1), red (F2), green (F3)

4.

The government want to set this pollution tax (Pigovian tax) such that 100 units of pollution will be abated, the government pollution-reduction goal. (note that the tax rate will not normally equal the number of units to abate, my example just worked out that way). Note how the efficient Pigovian tax equals what a permit would sell for if 100 permits were issued.

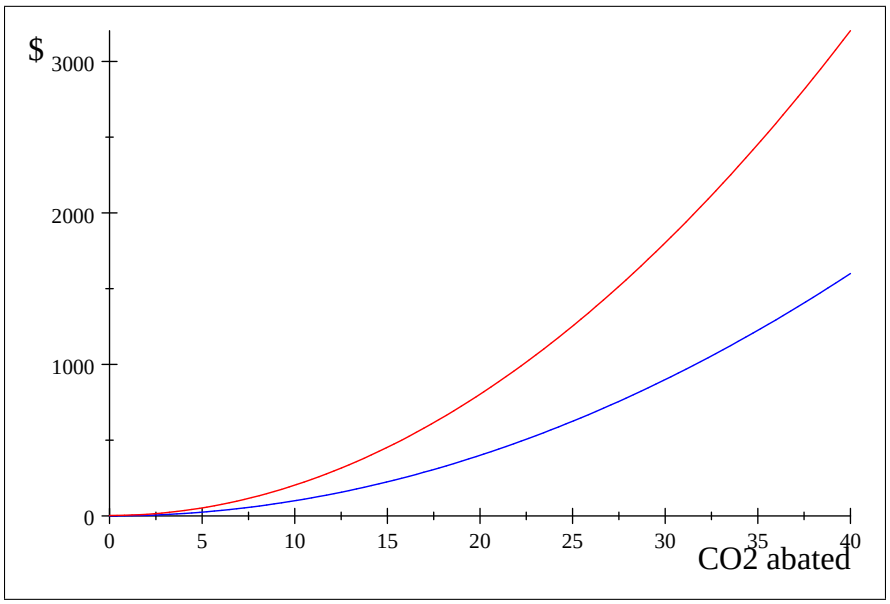
The solution for the KW two-firm problem is shown in the right-hand-side of the KW graph above.

3 An application of what we just learned.

If we want to reduce global CO_2 emissions we want most of the reductions to occur in poorer countries such as China rather than in the U.S. and Europe. Why is that?

The marginal cost of reducing CO_2 emissions is, for example, lower in China than in the U.S.

For example (I am making up the numbers),



marginal cost of reducing CO_2 emiss.: China blue, U.S. red

Consider, for example, heating a house: my house is insulated, I have double-pane windows and I have a gas furnace with not much energy loss. This is not true of the typically house in China. So imagine you want to spent $100 on added insulation to reduce CO_2 emissions. Should you insulate my house more or insulate a house in China that currently has no insulation. Or consider a typical bus in Boulder vs. a typical bus in Bangkok. If you have $100 to spend on reducing bus emissions where will you get the biggest bang for your buck.

Efficiency reguires we abate where it is cheapest to abate.

You might argue that is not fair to make the Chinese abate because historically we, not the Chinese, are the big CO_2 emitter. Note that I did say who, from an equity point of view, should pay for insulating houses in China. Who pays is the equity question. Maybe we should pay. The equity argument would be that we caused the problem, not them, and we are richer so have a higher wtp to solve the problem.

Note that like everthing else we want the efficient amount of CO_2 emissions (the efficient amount of global warming). And it is unlikely that the efficient amount of global warming is zero.