EC313 Lecture #9
Taxes and quotas

Matthew A. Turner
University of Toronto

Fall 2011

(*Updated 27 September 2011*)

Introduction

During the first part of the course we worked up to a characterization of the optimal time path for CO_2 emissions.

Last time, we investigated the incentive problem that leads a market or decentralized economy to emit too much CO_2 relative to these optima.

Today we examine two of the basic regulatory instruments, taxes and quotas, available for reducing emissions (and talk briefly about 'privatization').

Both are widely used for no-CO_2 pollutants, and both are commonly proposed in the context of CO_2 emissions, e.g., Hansen's quota of zero on coal, Kyoto's cap on CO_2 emissions for signatories.

Our objective is to understand how costly it is to achieve a given reduction in pollution/emissions with each instrument as conditions vary. This will help us to choose the least costly approach to mitigation.

Regulating a single firm under certainty

Consider a steel mill which pollutes 'too much' because they do not account for the fish killed by pollution/effluent.

Three candidate solutions:

- 'privatization' – steel mill buys the fishery (or vice-verse)
- A quota on steel or pollution production
- A (Pigouvian) tax on steel or pollution production

Example:

- y – units of steel
- p – price of steel
- $C(y) = \alpha y^2$ - cost of a unit of steel (for example)
- $C_s(y) = \beta y^2$ - social cost of pollution from a unit of steel (for example)

Note that we have increasing marginal cost of steel and pollution. Each unit is more expensive than the one before.

A profit maximizing steel mill owner solves

$$\max_y py - c(y)$$

The first order condition is

$$p = c'(y)$$

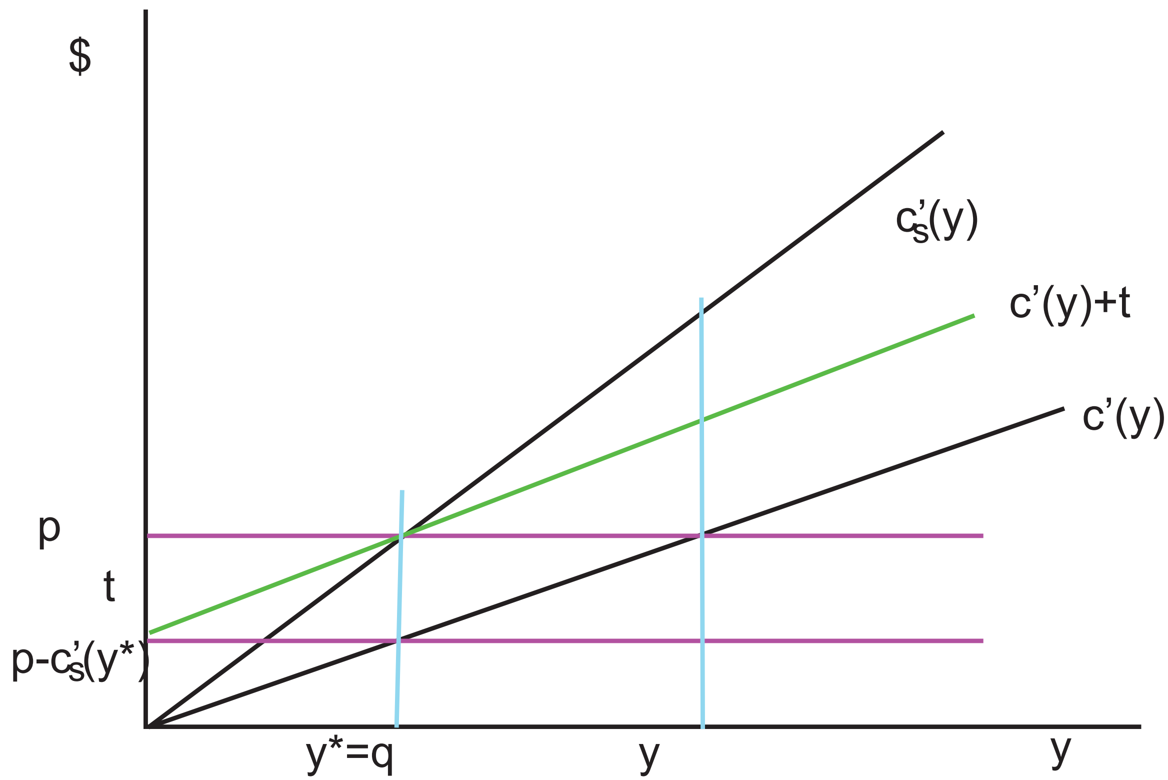
If we account for the cost of pollution, the socially optimal production of steel solves:

$$\max_y py - c(y) - c_s(y)$$

The first order condition is

$$p = c'(y) + c_s'(y)$$

These are not the same, and since c' and c_s' are increasing, we'll have too much steel in the market equilibrium.



$
c'_s(y)
c'(y)+t
c'(y)
p
t
p-c'_s(y*)
y*=q
y
y

Privatization

The first fix for this problem is ‘privatization’. Economists often talk about this as a solution to externality/incentive problems, but it is not really very well defined.

In this case, privatization requires some reorganization ownership so that the same people own the steel mill and the fishery. In this case, this new owner solves,

$$\max_y py - c(y) - c_s(y)$$

Since this is the planner’s problem, this will give us the optimal amount of pollution.

The implied assumption is that the steel mill owner is just as good at running a fishery as was the old owner of the fishery. This is not obviously true.

It is not obvious how this intuition is useful if we replace ‘pollution’ with CO_2 in this example. Who would buy what?

Quota

The second fix is to impose a quota. If $q*$ is the solution to the planner's problem, then we can impose a 'quota' on steel prohibiting the production of more steel than $q*$.

Then the profit maximizing steel mill owner solves A profit maximizing steel mill owner solves

$$\max_y py - c(y)$$
$$\text{s.t. } y \leq q*$$

Since the quota is binding, the solution to this problem is for the mill to produce $y = q*$.

Pigouvian tax

The third fix is to impose a tax on steel (called a Pigouvian tax after Pigou) that causes the profit maximizing mill owner to reduce output to the socially optimal level.

With a tax τ each unit of steel, the profit maximizing mill owner solves

$$\max_y (p-\tau)y - c(y)$$

The first order condition is

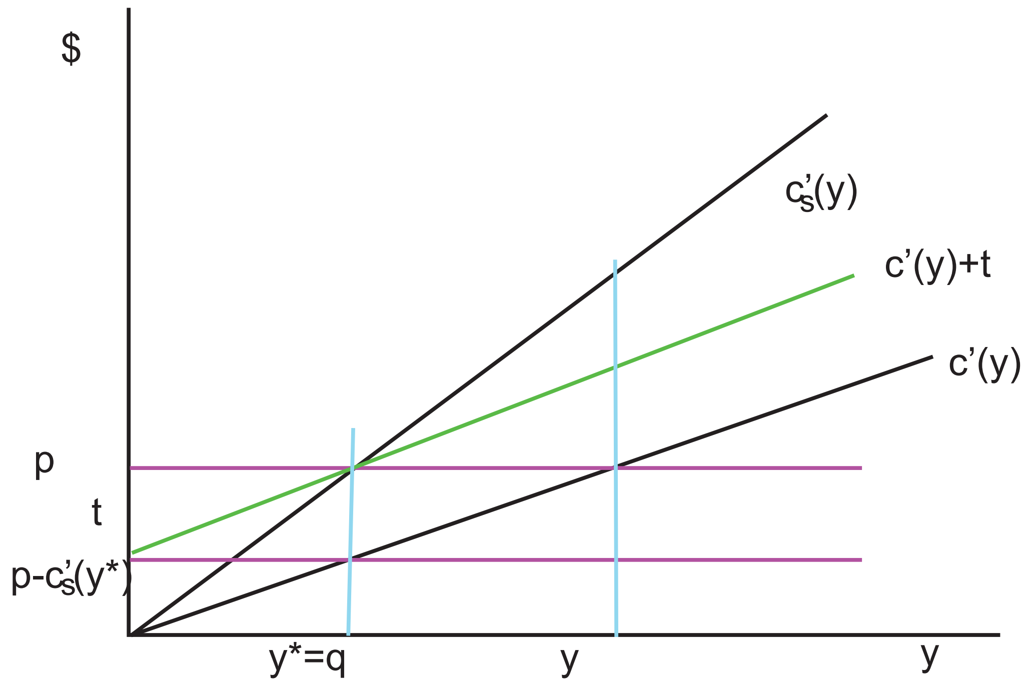
$$p - \tau = c'(y)$$

If we choose $\tau = c_s'(q^*)$, then this is

$$p - c_s'(q*) = c'(y)$$

the solution to this is to choose $y - q^*$.

We can show the effect of this tax graphically by either reducing the price line by $c_s'(q^*)$ or by shifting $c'(y)$ up by $c_s'(q^*)$.



There is a strong preference among professional/academic economists for taxes over quotas. However, in this model, there is no basis for this preference.

Both quotas and taxes get to the optimum at the same cost, so there is no basis to prefer one to the other.

The firm, however, will prefer quotas. Why?

Regulation of a single firm under uncertainty

We have seen that taxes and quotas equivalent, accomplish a given reduction in pollution at the same cost, when we are regulating a single firm with no uncertainty. (distributional effects are different)

Now suppose that the regulator is uncertain about social costs and benefits of regulation.

Notation

- y – air quality (note change from talking about pollution)
- $B(y)$ – social benefit of air quality y
- $C(y)$ – firm's cost to produce air quality y.

Story: We want to regulate a smoke stack which produces a local pollutant like fine particulates. As soot goes down, air quality goes up. $C(y)$ is the firm's cost of reducing soot to achieve air quality y. $B(y)$ is the value to society of air quality y.

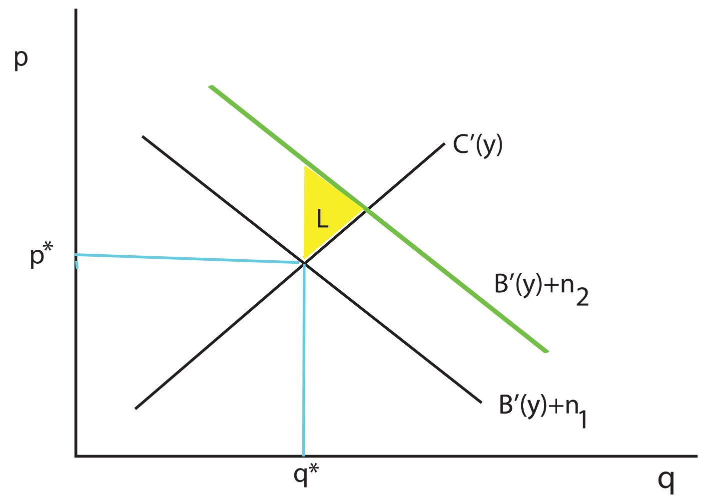
In this problem, the firm solves

$$\max_y py - C(y)$$

The planner wants

$$\max_y B(y) - C(y)$$

The planner can enforce this optimum by imposing $p = p^*$ or $y = q^*$.



This is just like the steel mill example, but with different notation: price and quantity regulation are equivalent.

p^* is 'price based regulation'. Rather than choosing a tax to change the price, to make things simpler, we're just choosing the price.

Imposing q^* is 'quantity based regulation', like a quota. To simplify things, however, we're not allowing the production of less (more). The firm does exactly what we tell it.

Aside: Why triangles measure welfare

The area between the marginal benefit and marginal cost curves for $y \in [y_0, y_1]$ is

$$\begin{aligned}\Delta W &= \int_{y_0}^{y_1} B'(z) - C'(z) dz \\ &= [B(z) - C(z)]_{y_0}^{y_1} \text{ (by the fundamental theorem of calculus)} \\ &= [B(y_1) - C(y_1)] - [B(y_0) - C(y_0)]\end{aligned}$$

which is the change in welfare, as required.

Benefits uncertainty

Now suppose the planner is uncertain about benefits, say because the health benefits of reductions in fine particulates are not well known, or because there is uncertainty about the benefits of reducing CO_2 .

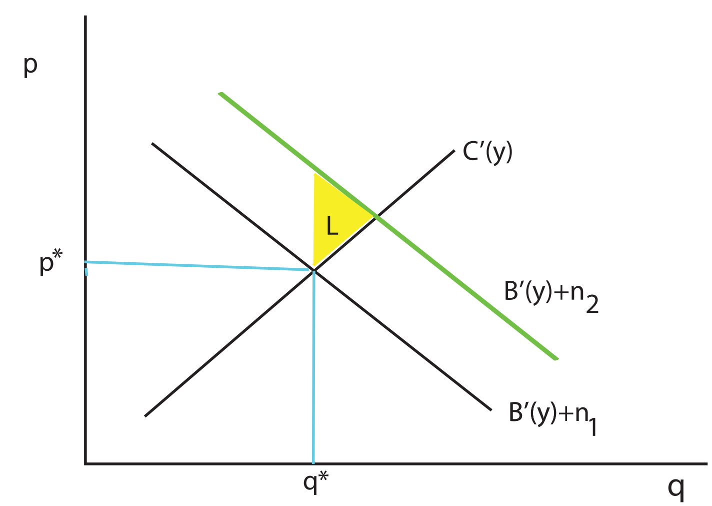
To formalize this, let η be a random variable, $\eta = (\eta_1, \eta_2, p, 1 - p)$ and suppose that

$$B'(y) = \eta + B''y$$

That is, the intercept of marginal benefit $B'(y)$ is unknown, but the slope is certain.

Suppose the planner chooses q^*. Then if η_1 occurs, the planner is at the optimum. If η_2 occurs, then air quality is 'too low' and there is a loss of welfare with value L.

Exactly the same thing occurs if the planner chooses p^*!



With benefits uncertainty, there is still no basis for preferring one type of regulation to the other. Each elicits the same behavior in both states of the world. Why? Uncertainty does not affect firm's behavior.

Cost uncertainty

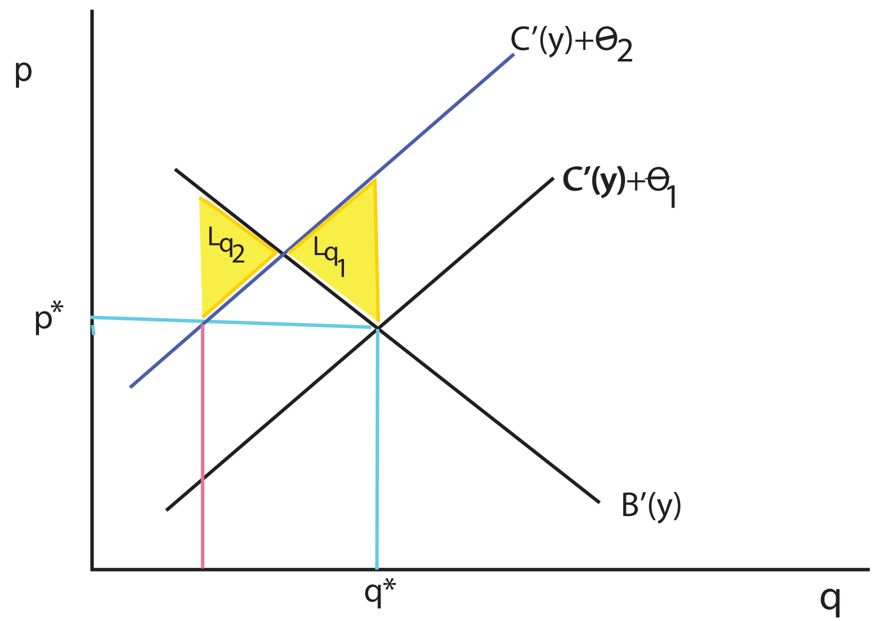
Now suppose that benefits are certain, but costs are uncertain.

Let θ be a random variable, $\theta = (\theta_1, \theta_2, p, 1-p)$ and let the cost function depend on θ:

$$C'(y) = \eta + C''y$$

This is similar to the way we described benefits uncertainty. The intercept of C' is random but slope is certain.

In this case, with price based regulation, the firm will choose y so that $C'(y) = p^*$. This means that the firm chooses different Y's as θ varies. With quantity based regulation, the firm always does what it's told, which is to choose $y = q^*$. Thus, with price uncertainty, we'll get different behavior under the different types of regulation.

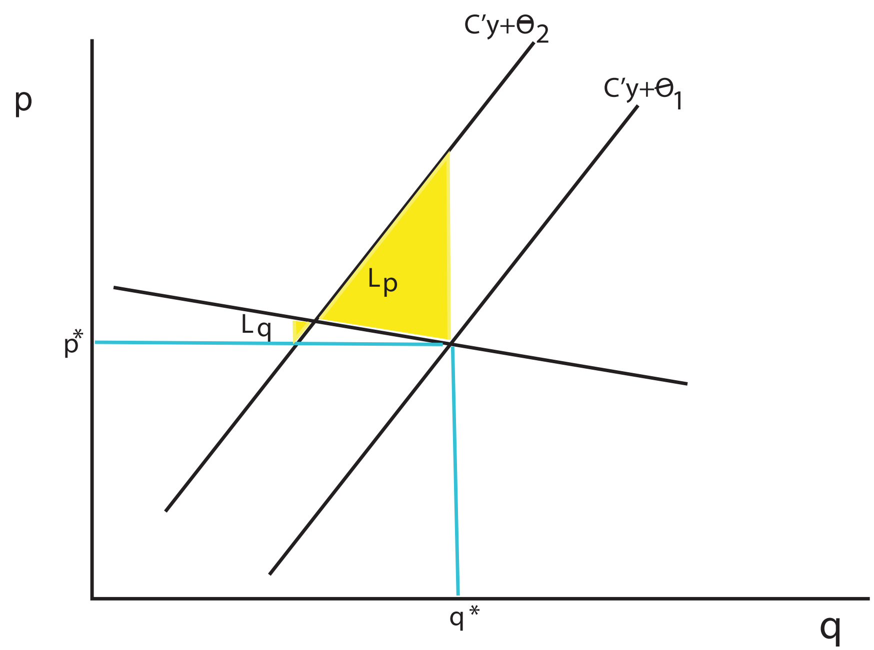


As drawn (not optimal), with $\theta = \theta_1$ there is no loss with either type of regulation. With $\theta = \theta_2$ lose L_{q_2} under price based regulation and L_{q_1} under quantity based regulation.

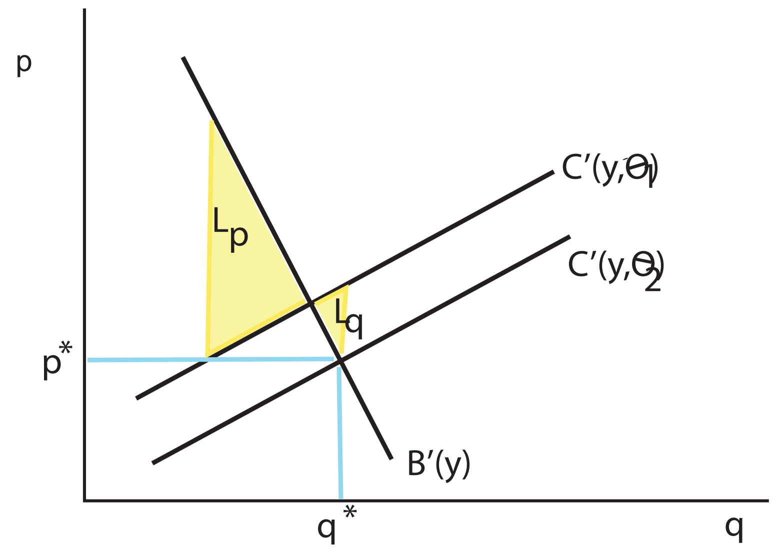
Thus, in this figure, choose price or quantity regulation depending on whether $L_{q_1} < L_{q_2}$ or not.

p vs q?

When marginal cost curves are steep relative to marginal benefit curves, this calculation favors price regulation.



Conversely, when marginal benefit curves are steep relative to marginal cost curves, this calculation favors quantity regulation.

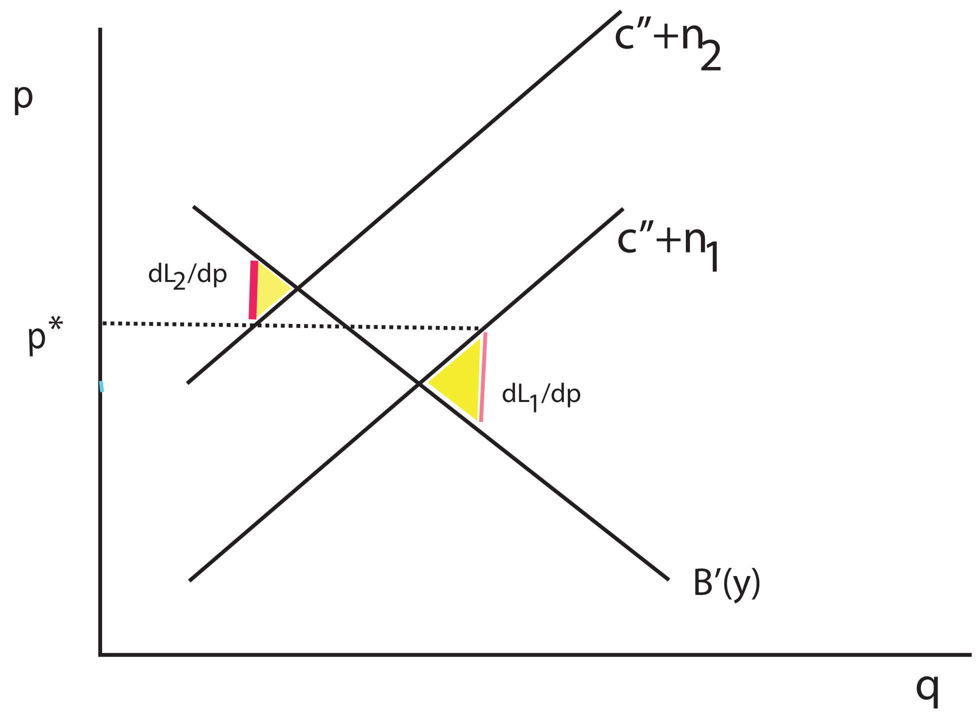


Loosely, if there is a ‘threshold’ value of benefits, we don’t want to goof around price based regulation that could land us on the wrong side of the threshold. Conversely, if there is a threshold in costs.

Optimal p vs optimal q?

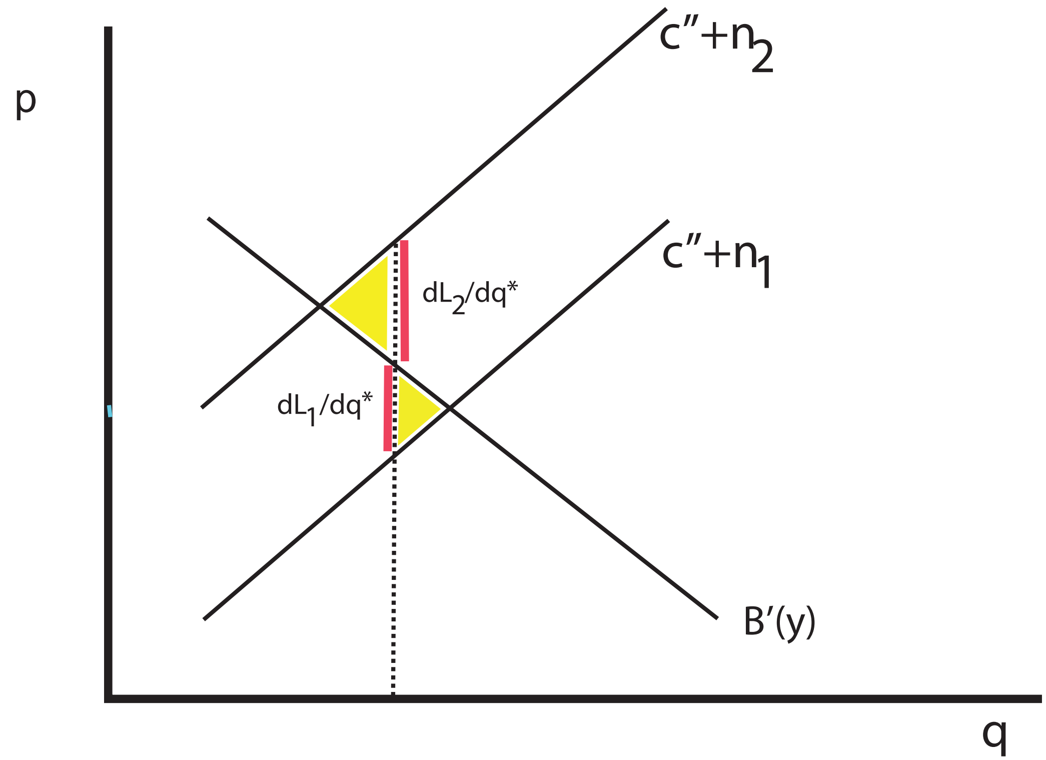
We would like to do is to compare OPTIMAL price and quantity regulation. For $\eta = (\eta_1, \eta_2, q, (1-q))$, choose p so that

$$q \frac{dL_1}{dp} = (1-q) \frac{dL_2}{dp}$$



To calculate optimal quantity regulation. For $\eta = (\eta_1, \eta_2, q, (1-q))$, choose q^* so that (NB: using 'q' two ways)

$$q\frac{dL_1}{dq^*} = (1-q)\frac{dL_2}{dq^*}$$



p vs q analytic

$$B'(y) = y - \frac{1}{2}B''y^2,\ \ B'' > 0, \text{ marginal benefit}$$
$$C'(y) = \eta y + \frac{1}{2}C''y^2,\ \ \text{marginal cost}$$
$$\eta = (0,1,\frac{1}{2},\frac{1}{2})$$

- Planner's objective is to solve

$$\max_y W = E(B(y) - C(y))$$

by choice of quantity or price regulation.

- To solve, compare welfare under best price and best quantity regulation.
  - Find best quantity regulation q^*
  - Find firm's response function for price regulation, e.g. $\hat{y}(\hat{p})$ that solves $\max_y py - C(y)$.
  - Choose $\hat{p}$ to solve $\max_p E(B(\hat{y}(p)) - C(\hat{y}(p)))$
  - Choose whichever type of regulation maximizes W

NB: $E(\eta^2) = \frac{1}{2}0^2 + \frac{1}{2}1^2 = \frac{1}{2}$