China's Rate-Based Approach to Reducing CO_2 Emissions: Attractions, Limitations, and Alternatives

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ONLINE APPENDIX

This appendix analyzes the relationship between alternative means of allocating emissions allowances and firms' marginal abatement costs. We first consider the case where the quantity of allowances offered to the firm is exogenous to the firm's level of output. We then compare this situation with the case where the firm's allocation of allowances depends on its level of output, as in China's ETS.

Case 1: Allowance Allocation Independent of Output

We consider the case involving a competitive firm. The firm regards its output price and the price of its input(s) as exogenous. The market price of emissions allowances is also exogenous to the firm. For simplicity, we assume there is just one priced input, though the results are the same with multiple priced inputs.

Let y represent the firm's output, and let y be a function of its input x and level of CO_2 emissions, e: $y = f(x,e)$, with $\partial f / \partial x > 0$ and $\partial f / \partial e > 0$.

The firm chooses x and e to maximize profits, given a_0, its allowance allocation, and given p, p_x, and p_a, which respectively represent the prices of output, the input x, and the market-equilibrium allowance price.

$$\pi = p \cdot y - p_x x - p_a (e - a_0)$$

The profit equation implies:

$$d\pi / de = p\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{dx}{de}\right) - p_x \frac{dx}{de} - p_a$$

Setting this derivative equal to zero yields the first-order condition:

$$(1) \qquad p\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{dx}{de}\right) - p_x \frac{dx}{de} = p_a$$

The left-hand side is the marginal benefit from emissions – or the negative of the marginal cost of emissions abatement. The marginal benefit consists of the induced increase in the gross value of output (first term) plus the decrease in cost of the input x (second term). If x and e are gross substitutes in production, dx/de will be negative, implying that increasing emissions entails an increase in x.

In the absence of other market failures, the negative of the above equation – the marginal abatement cost -- represents the marginal resource cost (ignoring environmental benefits) to both the firm and society. To maximize profits, the firm equates its marginal abatement cost to its marginal benefit, which is given by *-p*, the value of the avoided emissions allowance purchase made possible by the reduction in emissions. If all firms follow equation (1), the social costs of meeting the given aggregate emissions cap $\sum_i a_{oi}$ will be minimized, since each for all firms the marginal social costs of abatement are the same.

Case 2: Allowance Allocation Depends on Output

This case applies to China's new ETS. Under rate-based system, the firm receives an initial allocation a_0 at the beginning of the period and additional allowances a_1 at the end of the period. a_1 represents the additional allowances consistent with the firm's end-of-period output level y_1 and its benchmark emissions-output ratio β. Note that, depending on the firm's actual emissions, the firm might need to purchase additional allowances beyond the total $a_0 + a_1$ that it received from the government to be in compliance, or might be able to sell some of its allowances and still remain in compliance.

In this case, the profit equation is:

$$\pi = p \cdot y - p_x x - p_a (e - a_0 - a_1)$$

This equation differs from the profit-equation in Case 1 because of the presence of a_1. The first-order condition for profit-maximization is:

$$(2) \qquad d\pi / de = p\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{dx}{de}\right) - p_x \frac{dx}{de} - p_a\left(1 - \frac{da_1}{de}\right)$$

a_1 is given by

$$a_1 = \beta \cdot y_1 - \alpha \cdot \beta \cdot y_0$$

where β is the benchmark emissions-output ratio assigned to the firm, y_0 and y_1 are end-of-previous-period and end-of-current-period output, respectively, and α is an "initial allocation factor" with a value less than 1, employed to help assure that a_1 is not negative, as discussed in the main text. The first right-hand-side term is the number of allowances the firm is entitled to at the end of the period, while the second right-hand-side term is the same as a_0 above; it is the number it received at the beginning of the period and it is exogenous to the firm in the current period. Importantly, a_1 depends on the firm's output during the current period:

$$\frac{da_1}{de}=\frac{d}{de}\left(\beta y_1\right)=\beta\frac{dy_1}{de}>0$$

Substituting for da_1/de in (2):

$$d\pi / de = p\left(\frac{\partial f}{\partial e}+\frac{\partial f}{\partial x}\frac{dx}{de}\right)-p_x\frac{dx}{de}-p_a\left(1-\beta\frac{dy_1}{de}\right)$$

Setting the above expression equal to zero and rearranging gives:

$$(3) \qquad \underbrace{\underbrace{p\left(\frac{\partial f}{\partial e}+\frac{\partial f}{\partial x}\frac{dx}{de}\right)-p_x\frac{dx}{de}}_{MBsoc}+\beta p_a\frac{dy_1}{de}}_{MBfirm} \;=\; p_a$$

Paralleling equation (1) for Case 1, equation (3) indicates the marginal benefit from emissions on the left-hand side and the marginal cost of emissions on the right-hand side. The difference from equation (1) is the presence of the far-right term on the left-hand side. This term represents the marginal benefit from the induced increase in emissions allowances associated with the increase in output. Thus, the marginal benefit function is higher in this case: when evaluated at some value for *e*, the marginal benefit of an increment to emissions is higher than in the case where the firm's allowance allocation is independent of its output. Equivalently, when evaluated at any value for *e*, the marginal cost of an incremental emission reduction is higher in this case, since the opportunity cost (foregone marginal benefit) is greater. The subsidy component, represented by the term $\beta p_a(dy_1/de)$, creates a wedge between the marginal benefit to society from emissions (shown as *MBsoc* above) and the marginal benefit to the firm from emissions (shown as *MBfirm* above). The subsidy term is not an element of marginal social benefit because it is a transfer rather than a resource cost.

Equivalently, one can write the above equation as:

$$(3') \qquad p\left(\frac{\partial f}{\partial e}+\frac{\partial f}{\partial x}\frac{dx}{de}\right)-p_x\frac{dx}{de} \;=\; p_a-\beta p_a\frac{dy_1}{de}$$

which indicates that, from the firm's point of view, the effective price of an emissions allowance (right-hand side) is lower than p_a. Thus, firms will prefer to purchase more allowances (for a given market-equilibrium price p_a) than in Case 1.

Three key implications of the above analysis (discussed in the main text) are:

(1) the gap between *MBfirm* and *MBsoc* limits the ability of emissions trading to promote cost-effectiveness;

(2) this gap implies that heterogeneity of benchmarks hampers cost-effectiveness more in a rate-based system than in a comparable mass-based system; and

(3) the subsidy element compromises efficiency by leading to inefficiently low output prices that distort consumer choices between carbon-intensive and other goods.