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

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China is launching what is expected to become the world's largest carbon dioxide (CO_2) emissions trading system (ETS). Focusing initially on the electric power sector—which is responsible for a third of China's CO_2 emissions—the program aims to add major industrial sectors, eventually covering more than half of the country's total emissions. Emissions trading may occur across all provinces and covered sectors. The new system will help China meet its Paris pledge of a 60–65 percent reduction in CO_2 emissions by 2030.

Virtually all existing national and subnational cap-and-trade programs are mass-based. In such programs, the number of allowances the regulator allocates to covered facilities is established in advance of the compliance period; it does not depend on facilities' production levels within the compliance period.[1]

A distinguishing feature of China's new ETS is its rate-based structure: the number of allowances granted to a facility depends on its emissions-output ratio at the end of the compliance period. This means that a facility can influence its allowance allocation through its production choices during the compliance period, since the level of output is the denominator of the ratio.

The rate-based structure has important implications for firms' incentives regarding facilities' production levels and emissions abatement. This paper looks closely at the rate-based aspect of China's new program and assesses what it implies for efficiency, cost-effectiveness, and equity.

I. Structure

A. *Allowance Allocation*

To allocate allowances to covered facilities, most existing ETSs rely on benchmarking, which bases the number of allowances granted to a facility on a technology- or industry-specific emissions-output ratio.[2] Note that, even if it employs benchmarking, an ETS is mass-based so long as the number of allowances granted to a facility for a given compliance period is pre-established rather than a function of the facility's output during that period.

China's nationwide ETS also relies on benchmarking but applies it differently from the way it is used in mass-based systems. A key difference is the use of end-of-period updating of the allowance allocation. At the start of the compliance period, a covered facility's allocation is its output from the previous compliance period, y_0, multiplied by the facility's designated benchmark emissions-output ratio, β, and an "initial allocation factor," α. The initial allocation factor and the benchmark ratio are set by the regulatory authorities.[3]

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[1] If a facility's level emissions exceeds the fixed number of allowances it was granted, it can remain in compliance by purchasing additional allowances on the emissions trading market. If the facility's emissions fall short of its cap, it can benefit by selling its excess allowances on that market.

[2] For example, the regulator might apply the benchmark β to a given facility by granting it $\beta^* y_0$ allowances for the compliance period, where y_0 is some pre-established reference level of output.

[3] At the time of this writing, China has not yet specified the value it will employ for a, although a 0.6 value has been widely discussed. With a value of 0.6 for α, the facility would initially receive 60 percent of the allowances it would need to justify the emissions-output ratio β if its level of output did not change from that of the previous period.

The second step in the process is at the end of the compliance period, when a covered entity receives additional allowances sufficient to bring the ratio of total allowances to output over the entire period in conformity with the specified benchmark emissions-output ratio. The needed quantity of additional allowances is given by the formula:

$$(1) \qquad a_1 = \beta y_1 - \alpha\beta y_0,$$

where y_1 is end-of-period output and α_1 represents the additional allowances given to the firm at the end of the period. The first term on the right-hand side is the total number of end-of-period allowances consistent with the benchmark ratio. The second is the number distributed to the covered facility at the beginning of the period. The difference between the two is the number of additional allowances needed.[4] The allocation's dependence on the end-of-period emissions-output ratio makes the Chinese system rate-based.[5] As discussed in Section II, this dependence on production levels has both attractions and limitations.

B. *Determinants of the Benchmarks*

The emissions reductions stemming from China's program will depend on the choice of benchmarks.[6] China's current plan is to distinguish 11 benchmarks for the power sector, differing according to the technology/fuel combination being used.[7]

In addition to strictly technological considerations, benchmarks may reflect differences in regional economic development. Duan and Zhou (2017) show that cross-provincial differences in development levels are substantial: average per capita income varies by more than 300 percent across the provinces, while average energy intensity differs by over a factor of six. While nominally defined in terms of fuel and technology factors, China's benchmark categorization scheme also reflects cross-provincial differences in economic development.

Heterogeneity of benchmarks can compromise cost-effectiveness of an ETS, particularly when transactions costs or other elements impede emissions trading. In Section II we show that in a rate-based system, heterogeneous benchmarks can be particularly problematic, hampering cost-effectiveness even when allowance trading is perfectly fluid.

II. Attractions, Limitations, and Alternatives

A. *Attractions*

Beyond its important international implications, the new ETS offers several potential domestic rewards. Its broader sectoral and geographical coverage (relative to the earlier pilot ETS programs) promotes cost-effectiveness by allowing additional low-cost opportunities for emissions abatement to be exploited.

The rate-based structure also offers attractions. A key advantage of issuing allowances based on a ratio of emissions to actual output during the compliance period is that it can more easily adapt to economic conditions. Since output is in the denominator, the amount of emission reduction needed for compliance adjusts automatically to current economic conditions. If the economy is booming (high output), the allowable level of emissions increases. If the economy is in a slump (low output) the allowable emissions are more limited. This flexibility can help avoid exceptionally high allowance prices and abatement costs during boom times,

[4] It is theoretically possible for a_1 to be negative—for a facility to receive excessive allowances at the beginning of the period. This happens when y_1 is lower than αy_0. Also, each province has the option of reducing the allocation of allowances to facilities within the province if it wishes to make the program more stringent locally. A reduction corresponds to a lower value for β in equation (1). It is also our understanding that the central government will offer "reserve allowances" to some low-income provinces, additional allowances that these governments can allocate according to their own chosen criteria.

[5] A rate-based ETS is often termed a tradable performance standard.

[6] We do not have the planned benchmark values at the time of this writing. Historically, benchmarks have reflected a range of considerations, including technological, economic and institutional factors. For further discussion, see Goulder et al. (2017).

[7] Thus, for example, gas facilities are expected to have different benchmarks from coal units, and gas-boilers will likely have different benchmarks from those of combined-cycle generators. It is expected that for facilities in a given sector employing a given technology, the benchmark will be the recent emissions-output ratio at a certain point in the distribution of emissions-output ratios among the facilities in this category.

while helping assure that allowance prices do not plummet during economic slumps.[8]

A further attraction is the potential to use benchmarking to serve distributional objectives. Higher benchmark emissions-output ratios—more easily achieved by the entity to which the benchmark applies—can be assigned to the lower-income provinces to reduce their regulatory burden and thus soften the differential distributional impacts of a carbon pricing system.[9] This attraction is not unique to rate-based systems: mass-based systems also can employ differing benchmark stringencies to achieve distributional goals.[10]

B. *Limitations*

Certain limitations of the rate-based approach stem from the different incentives it yields for covered firms. Consider a firm that produces output y as a function of a single input x and emissions e: $y = f(x, e)$, with $\partial y/\partial x > 0$ and $\partial y/\partial e > 0$.[11] Assume that the firm is within a rate-based system, faces the benchmark emissions-output ratio β, and regards its output price, the price of its input x, and the price of emissions allowances as exogenous.

The firm's profit (π) is given by

$$(2)\quad \pi = p \cdot y - p_x x - p_a(e - a_0 - a_1),$$

where p is the output price, p_x is the price of input x, and p_a is the emissions allowance price. Let a_0 and a_1, respectively, represent the beginning-of-period and end-of-period (additional) allowances given to the firm, as indicated in equation (1). The firm's profit-maximization problem is to choose the optimal values for y and e, recognizing that it would need to hold $\beta \times y$ in allowances at the end of the period to be in compliance.[12]

The first-order condition for profit-maximization is:

$$(3)\quad d\pi/de = p\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{dx}{de}\right) - p_x\frac{dx}{de} - p_a\left(1 - \frac{da_1}{de}\right).$$

As shown in the online Appendix, the above expression implies:

$$(4)\quad \underbrace{\underbrace{p\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{dx}{de}\right) - p_x\frac{dx}{de}}_{MBsoc} + \beta p_a \frac{dy_1}{de}}_{MBfirm} = p_a.$$

The left-hand side of (4) is the benefit to the firm from an increment of emissions. It consists of the value of the induced change in output (first term) minus the change in the value spent on input x (second term) plus the value to the firm of the additional allowances offered as a result of the increase in output (third term). The right-hand side is the cost of an increment of emissions. The firm maximizes profits by choosing the level of emissions that equates these marginal benefits and costs.

The difference between equation (4) and the corresponding equation under a mass-based system is the presence of the term $(\beta p_a(dy_1/de))$ on the left-hand side of (4). This term represents the benefit to the firm from the induced increase

[8] Price spikes have occurred in existing national and regional ETSs. Regional Clean Air Incentive Market (RECLAIM) emissions trading program in the Los Angeles area initially had no mechanisms to adjust allowance supplies to changing macroeconomic conditions. In the summer of 2000, the combination of a booming economy and other factors caused allowance prices to jump dramatically. Average price per ton in 2000 exceeded \$20,000, up from \$257 in 1999.

[9] As mentioned earlier, it is also the case that China's central government has given the provincial governments the authority to lower the benchmarks in their area if they want to demonstrate a stronger commitment to emissions reduction.

[10] As indicated in below, a rate-based system tends to raise output prices by less than a mass-based system that achieves the same emissions reduction. While this might be viewed as an attraction, we note below that the smaller increase distorts consumption decisions and comes at a cost in terms of economic efficiency. See Boom and Dijkstra (2009), Fischer and Newell (2008), and Burtraw et al. (2014) for further discussion.

[11] The main results would be the same if a vector of inputs were considered.

[12] Thus, as indicated in equation (2), if the firm was initially given a_0 in allowances and its level of output entitles it to another a_1 in free allowances, then it will need to pay $p_a^*(e - a_0 - a_1)$ for additional allowances by the end of the period to be in compliance. If $e - a_0 - a_1$ is negative, it will be able to sell up to $e - a_0 - a_1$ of its allowances and remain in compliance.

in emissions allowances associated with the increase in output linked to an increase in emissions. Hence the marginal benefit function is higher in the case of a rate-based as opposed to mass-based allocation regime: when evaluated at any given value for e, the marginal benefit of an increment to emissions is higher than in the case where allowance allocation is independent of its output. The subsidy component, represented by the term $\beta p_a(dy_1/de)$, drives a wedge between the marginal benefit to society from emissions (*MBsoc* above) and the marginal benefit to the firm from emissions (*MBfirm* above). The subsidy term is not an element of marginal social benefit because it is a transfer rather than a resource cost.[13]

The gap between *MBfirm* and *MBsoc* compromises cost-effectiveness. Emissions trading reduces differences across firms in *MBfirm*, but cost-effectiveness is increased only to the extent that across-firm differences in *MBsoc* are reduced. To the extent that the *MBfirm-MBsoc* gap varies across firms, the reductions in across-firm differences in *MBfirm* from emissions trading will not correlate perfectly with reductions in across-firm differences in *MBsoc*, and thus emissions trading will be limited in its ability to promote cost-effectiveness.

Moreover, the gap means that heterogeneity of benchmarks hampers cost-effectiveness more in a rate-based system than in a comparable mass-based system. Varied benchmarks imply heterogeneity of the subsidy term $\beta p_a(dy_1/de)$ in (4) above, which in turn adds to differences across firms in the *MBfirm-MBsoc* gap. This reduces the potential for trading to lower costs. Indeed, cost-effectiveness is hampered even under perfectly fluid trading that leads to equality across firms in *MBfirm*.

The subsidy element also compromises economic efficiency (aggregate net benefits). Suppose that the benchmarks were optimally set in imposing the efficiency-maximizing ratios of emissions to output. Nevertheless, the subsidy means that the output prices from the covered sectors will be too low from an efficiency point of view. This implies a distortion in consumers' choices between the output from the covered (carbon-intensive) industries and the outputs from other industries.[14]

C. *Alternatives*

Important institutional and political challenges aside, the key alternative to the rate-based approach is a mass-based system. This alternative would forfeit the ability of China's current rate-based system to adjust emissions allocation levels automatically in response to macroeconomic booms and busts. It would also tend to yield higher prices of emissions-intensive goods.

However, moving to a mass-based system would also confer significant benefits. First, because a mass-based system has greater potential to reduce the *MBfirm-MBsoc* gap, it would enhance the ability of allowance trading to promote cost-effectiveness. Second, as discussed, it would reduce the extent to which heterogeneity of benchmark stringencies handicaps cost-effectiveness. Third, by eliminating the implicit subsidy to output that the rate-based system produces, it would reduce distortions in the relative prices of carbon-intensive and other goods, thereby enhancing efficiency, other things equal. Fourth, it would reduce administrative burdens, since there would be no need to track firm-level output for compliance purposes.

Another potential reform would be the promotion of more fluid trading across sectors and provinces. This would benefit China even if the system remained fully rate-based.[15] Steps to

[13] Equivalently, one can write equation (4) as

$$p\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{dx}{de}\right) - p_x\frac{dx}{de} = p_a - \beta p_a\frac{dy_1}{de}, \tag{4'}$$

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 a mass-based system involving the same benchmarks.

[14] This result has been obtained in Fischer (2001), Holland, Hughes, and Knittel (2009), and Fowlie (2012). It may be noted that, compared with the mass-based system, the rate-based system does not necessarily sacrifice efficiency in terms of the aggregate level of emissions. Suppose the optimal level of aggregate emissions in the absence of the subsidy (that is, under a mass-based system) is E. And suppose the array of benchmarks β gives rise to an aggregate level of emissions in the mass-based system below E. Then the rate-based system could be more efficient, i.e., larger net benefits relative to the unregulated status quo, by leading to a higher E.

[15] In previous pilot programs for SO_2 cross-provincial trades were sometimes restricted out of a concern that such trades could limit a provincial government's ability to meet other emissions-related requirements, or out of a concern

bring about more fluid trading across sectors and provinces include strengthening the program's legal foundation; achieving more credible and consistent emissions measurement, reporting, and verification; and instituting comprehensive program review and adjustment.

III. Conclusion

China's introduction of a national ETS is a major step toward the global goal of addressing global climate change. At this early stage it is already clear that the system seriously confronts important efficiency and distributional issues. Yet converting from the rate-based structure to a mass-based system could offer important benefits in terms of both cost-effectiveness and economic efficiency. Within the current rate-based system, reducing the heterogeneity of the benchmarks and removing residual impediments to trading would further enhance cost-effectiveness. And greater reliance on direct income transfers rather than heterogeneous benchmarks could help meet distributional objectives.

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that sufficient allowances might not be available within a province to meet future demand (Zhang et al. 2016; Tao and Mah 2009).