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ABSTRACT

Jurisdictions employing emissions trading systems (ETSs) to control emissions often utilize other environmental or energy policies as well, including policies to support renewable energy and reduce energy consumption. Interactions with these other policies lead to different outcomes from what might be predicted by examining the policies separately. The prior literature considering policy interactions has focused mainly on the case where the ETS is cap and trade. This paper extends the literature by examining the outcomes under a wide range of ETSs (including several forms of tradable performance standards) and overlapping policies (including various renewable subsidies and electricity consumption taxes). An analytical model demonstrates that the impacts of overlapping policies on allowance prices, emissions, and electricity output depend critically on the nature of the ETS. A numerical general equilibrium model tailored to China's economy explores the implications for the cost-effectiveness of emissions reductions. Results indicate that overlapping policies that reduce cost-effectiveness under cap and trade can significantly enhance cost-effectiveness under tradable performance standards. The model predicts that under the current and planned designs for China's ETS, which sets differentiated tradable performance standards for emitters, implementing renewable portfolio standards and accounting for indirect emissions from electricity consumption are both beneficial. Together they can reduce the cost of achieving the national emissions target by 20-30 percent over the interval 2020-2035. Transitioning to uniform benchmarks for emitting power generators could save another 10-15 percent. The findings highlight the importance of coordinating the designs of emissions trading systems with the overlapping policies.

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I. Introduction

Economists for years have urged policy makers to adopt market-based mechanisms for controlling emissions of pollutants like greenhouse gases (GHGs). More and more jurisdictions have been introducing carbon pricing, either through carbon taxes or via tradable allowance systems (World Bank, 2022). Importantly, these jurisdictions typically have other energy or environmental policies in place, including support for renewable energy to promote the transition to a low-carbon economy. This overlap of policies leads to economic interactions that give rise to outcomes quite different from what one might predict after examining the individual policies separately. The overlaps affect outcomes for emissions, the prices of emission allowances, and levels of production.

A substantial literature has evolved to look at interactions between overlapping market-based policies. Most have focused on the response of emissions tax and cap-and-trade (CAT) systems to additional interventions such as various supports for renewable energy (Sijm, 2005; De Jonghe *et al.*, 2009; Böhringer and Rosendahl, 2010; Fischer and Preonas, 2010; Fankhauser *et al.*, 2010; and Flues, Löschel *et al.*, 2014; Böhringer and Behrens, 2015).

The prior literature has often contrasted the case where a new policy intervention overlaps with an emissions tax (e.g., a carbon tax) and the case where it overlaps with an emissions trading system. In the former case, the emissions prices are fixed by statute; in the latter, these prices are determined by supply and demand in the market for allowances. The new intervention affects the shadow cost of meeting the regulatory obligations, thereby affecting emissions prices under CAT, a phenomenon that has come to be known as the “waterbed effect.” An example of this effect: when a binding renewable energy target is introduced in the presence of a CAT system, the requirement for more renewables than the market would otherwise provide lessens the need for other abatement measures to meet a binding emissions cap. This fall in demand for allowances causes emission prices to decline. Meanwhile, total emissions remain unchanged, as this total is determined by the emissions cap.

This paper extends the literature by considering the implications of overlaps for a wider range of emissions trading systems (ETSs), including not only cap and trade (CAT) but also several forms of tradable performance standards (TPSs). We also consider a range of policies with which the ETS overlaps, including subsidies to renewables and taxes on electricity. We present analytical results that contrast the impacts of the different types of overlaps. We then describe and apply a numerical general equilibrium model that indicates quantitative impacts in the context of China's economy.

Both the type of ETS and the type of overlap matter. CAT is a mass-based ETS: the total quantity (mass) of allowable emissions for each compliance period is pre-determined.[1] However, TPSs, which are rate-based, are becoming more prevalent for emissions control. Under a TPS, the firm's allocation of allowances is endogenous to its production level: it is the product of the firm's assigned benchmark and its level of output. The endogeneity of the allocation implies that aggregate emissions will vary with the level of economic activity. The conditional allocation implicitly subsidizes output, since additional production generates additional emission allowances (Fischer, 2001). Correspondingly, the subsidy discourages the use of output reductions or conservation as mechanisms for reducing emissions.

Within the general TPS category, there are several varieties. Some set a uniform sector-wide performance standard for fossil- and non-fossil-based producers alike, such as a maximum emission intensity per kWh of generation from all sources. Others employ benchmarks that differ depending on (status quo) emissions intensities. Systems with differing benchmarks include China's ETS for CO_2 (Goulder *et al.*, 2022, 2023) and Canada's federal and provincial output-based pricing systems for power and industrial sectors, which use intensity standards and credit trading. Under these TPSs, sources with higher emissions intensities face higher (less stringent) benchmarks, and non-emitting sources are unregulated and receive no benchmarks. We will use the label "SPS" for a rate-based ETS in which the performance standard is applied sector-wide, covering both fossil- and non-fossil-based producers. In contrast, we will apply the label "EPS" (for "emitter performance standard") to refer to rate-based ETSs that cover only relatively high-emitting sources such as fossil-based power generators, while relatively clean or non-emitting sources are excluded from benchmark allocations. The US EPA's Affordable Clean Energy Rule (ACE) of 2019 is an example of an EPS: it establishes performance standards for existing coal-fired generators only, based on modest goals for heat rate (efficiency) improvements.[2]

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[1] In practice, some "flexibility mechanisms" within a CAT system can allow the number of allowances to vary.

[2] However, since the ACE excludes trading, it is not an EPS as defined in this paper.

The TPSs we consider will differ in terms of both coverage (sectoral or emitter) and in terms of whether the benchmarks are uniform or differentiated. We will focus primarily on the following four types of ETS: (1) cap-and-trade (CAT); (2) a uniform sector-wide performance standard (USPS); (3) a uniform emitter performance standard (UEPS), which imposes uniform standards on covered sectors but includes no benchmarks for clean sources; and (4) a differentiated emitter performance standard (DEPS), in which higher emitting categories among the fossil energy sources are afforded higher benchmarks. Table 1 displays the main features of the different ETSs.

The nature of the interactions between such rate-based trading systems and overlapping energy or environmental policies differs from the interactions of CAT with such policies, as this paper will reveal. Under a (well-enforced) CAT system, total emissions are determined by the cap, apart from potential leakage outside the relevant domain of the system. In contrast, under a USPS, the presence of an overlapping subsidy to renewable energy lowers generation costs and electricity prices, and the expansion of electricity consumption and output gives rise to larger allowance allocations and emissions. Under an EPS, an overlapping subsidy yields outcomes that differ from both the CAT case and the USPS case; in this case, an overlapping subsidy to low- or zero-carbon energy crowds out production from higher-intensity sources and thereby lowers overall emissions. Under all forms of TPS considered, an accompanying increase in taxes on electricity reduces electricity production from all sources and thereby contributes to reduced emissions.

Table 1. Features of Emissions Trading Systems Considered

Compliance Basis:	**Mass-Based**	**Rate-Based (Tradable Performance Standards, TPS)**		
Coverage:	**Designated Sectors or Emitters**	**Designated Sectors**	**Emitting Sectors Only**	
Benchmark Specification:			Uniform	Differentiated
ETS Description and Label:	Cap and Trade (CAT)	Uniform Sectoral Performance Standard (USPS)	Uniform Emitter Performance Standard (UEPS)	Differentiated Emitter Performance Standard (DEPS)

We derive these and other results analytically using an energy demand and supply model that considers a range of opportunities for fuel-switching and demand-reduction, as well as different types of emissions-control policies. The theoretical model reveals the effects of a range of potential policy overlaps, bringing out how the economic consequences differ depending on the combination of policies involved.

We complement this analysis with quantitative results using a numerical general equilibrium model that considers the different types of ETSs and overlaps. Its general equilibrium structure captures interactions across sectors and changes over time. The model is designed and calibrated to simulate the context of China's recent introduction of a nationwide TPS (specifically, a DEPS) to reduce CO_2 emissions. The issue of overlapping policies with rate-based trading is highly relevant to this new initiative, as the nation has also introduced overlapping subsidies to promote renewables-based electricity. Policy discussions suggest a significant possibility that China's ETS will be revised to address the current incomplete pass-through of electricity prices. We apply the numerical model to assess the impact of a range of current and potential overlaps under alternative ETS designs.

The numerical model yields unique and policy-relevant findings regarding the implications of policy overlaps. First, overlapping policies improve the cost-effectiveness of China's TPS (a DEPS), while reducing the cost-effectiveness of the CAT alternative. The overlaps in China's stated policy[3]—a renewable portfolio standard, which implicitly taxes electricity consumption to subsidize renewable energy, and an additional requirement that TPS-covered industrial sectors pay for their indirect emissions—reduce the cost disparity between China's DEPS and an equivalent CAT by two-thirds.[4] Second, combining the stated policy overlaps with China's DEPS is estimated to reduce the costs of meeting the given emissions reduction target by approximately 30%. Third, aligning renewable share targets more closely with China's emissions targets could further enhance the existing system's cost-effectiveness by approximately 10%. Fourth, reforming the ETS by phasing out differentiated benchmarks in the electricity sector could lower costs by 10%-15%, although the additional benefits from moving

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[3] This study employs the term "stated policy" to refer to the climate policies currently in place as well as those under development. Section IIIA provides a detailed discussion of these policies.

[4] China is contemplating transitioning from its DEPS to a CAT system. These findings suggest smaller benefits from such a transiton than what otherwise might be expected, absent reforms to the overlapping policies.

to a uniform, sector-wide performance standard are small in the presence of the given overlaps. These results highlight the need to consider the choice of ETS and overlapping policies together when undertaking reforms.

The rest of the paper is organized as follows. Section II offers the structure of the analytical model and derives and interprets results from that model under various types of overlaps. Section III offers results from numerical simulations of potential outcomes in China. Section IV presents the sensitivity analysis. Section V concludes.

II. Insights from theory

The theoretical model of energy and environmental markets builds on those of Fischer and Preonas (2010, henceforth FP) and Fischer (2009), which use linearized supply and demand functions to analyze incremental policy changes from an equilibrium point. The framework is simple yet general enough to incorporate multiple ETSs and overlaps. The theoretical model focuses on incentives to reduce overall emissions by switching from higher-emitting to lower-emitting sources or by reducing the supply of intended output (e.g., electricity). These incentives align with the crucial differences among the policies, which include the differences in implicit output subsidies created by different allowance allocation systems. The model abstracts from some activities that can make individual sources less emissions-intensive, such as the adoption of efficiency improvements or new abatement technologies. This simplification helps sharpen the focus of our analytical model. Key outputs from this model are the impacts of overlapping subsidies or taxes on emissions, allowance prices and output under various ETSs. These results provide a foundation for the quantitative results from our numerical simulations.

A. Model framework

The theoretical model considers the example of electricity generation, the industry most frequently regulated with emissions trading, but the results generalize to other industries as well. Four main types of generation are represented: higher-emitting fossil fuels f, such as coal; lower-emitting fossil fuels g, such as natural gas; non-emitting renewable energy r; and baseload technologies x, such as nuclear energy and large-scale hydropower, which are also non-emitting. Baseload generation is characterized as fixed and fully utilized generation capacity. Renewable energy sources include wind, solar, biomass, geothermal, and so on, and the structure also pertains to new, small-scale hydropower. Natural gas-fired generation has an emissions rate of m_g, while that from other fossil fuels has a higher emissions rate of $m_f > m_g$.

The model comprises a collection of upward-sloping, source-specific inverse supply curves and a single downward-sloping inverse demand curve,[5] thus offering the standard relationships between price (on the y-axis) and quantities (on the x-axis). Whereas the baseload supply curves are fixed and perfectly inelastic (i.e., $dx = 0$), the non-baseload types of generation are assumed to have inverse supply curves $S_g(g)$, $S_f(f)$, and $S_r(r)$ that are weakly upward-sloping ($S_i' \geq 0$ for all i); that is, the prices demanded by suppliers are either flat or increasing with generation load.[6] The inverse consumer demand function is $D(f+g+r+x)$, where $D' < 0$.[7] Let total output $Y = g + f + r + x$.

If markets are competitive, the supply curves can be interpreted as marginal cost curves. When these technologies receive competitively determined (i.e., exogenous) prices, their marginal costs are equal to the price received. More generally, the supply curves represent whatever price is demanded by producers for an additional unit of generation at the amount supplied. This characterization can then more generally encapsulate producer responses, such as in imperfectly competitive or regulated electricity markets; the key feature is that supply curves are upward-sloping. For our narrative, we will assume competitive markets.

Let P be the market price of electricity received by producers (the “wholesale price”). Policies to reduce emissions and promote renewables cause the after-tax prices received by suppliers to diverge according to the energy source and may also create a wedge between consumer (“retail”) prices and producer prices.

All of the major market-based policies for renewable energy and climate mitigation can be expressed as a combination of taxes and subsidies (see also Fischer and Newell 2008). We

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[5] Thus, the outputs of the industry are regarded as perfect substitutes.

[6] The symbols *f, g, r,* and *x* are used both to index the applicable industry and to indicate output levels. Steepness or flatness of the supply curves may depend on the timeframe being considered (short run or long run), and interactions with fossil fuel or land markets. We essentially assume that there are no increasing returns to scale for any overall supply curve.

[7] FP used direct demand, so our equations will have the inverse of those slopes.

consider three: a price on emissions *t*, a tax on electricity consumption *b*, and a production subsidy for renewables *s*. To this, we add a key feature of many tradable performance standards: namely, source-specific benchmarks or emissions rates that determine allowance allocations. The benchmarks are a_i, for $i=\{f,g,r\}$. We will refer to "$m_i - a_i$" as the net emissions rate for electricity from generator type *i*. The implicit subsidy to a source is the product of the benchmark and the emissions price. Since baseload generation sources are assumed to have fixed output, we ignore output-based allocations for these sources, which could equivalently be subsumed into a total lump-sum allocation, *A*. In practice, large existing nuclear and hydropower sources are frequently exempt from performance standards, both by virtue of being clean and the fact that their capacity is not possible to adjust.

The market-clearing conditions are simply that the inverse supplies and demand equal the relevant prevailing market prices, inclusive of applicable policy interventions:

$$\begin{aligned} S_g(g) &= P + t(a_g - m_g) \\ S_f(f) &= P + t(a_f - m_f) \\ S\ (r) &= P + s + ta_r \\ P + b &= D(g + f + r + x) \end{aligned}$$

To evaluate the effects of changes in different policy combinations on consumer prices, we first totally differentiate the market-clearing equations. From this, we derive a system of equations governing the responses to the different policies:

$$dP = \left(dg + df + dr\right)D' - db\,, \tag{1}$$

$$dg = \left(dP + dt(a_g - m_g)\right)/\,S_g'\,, \tag{2}$$

$$df = \left(dP + dt(a_f - m_f)\right)/\,S_f'\,, \tag{3}$$

$$dr = \left(dP + ds + a_r dt\right)/\,S_r'\,, \tag{4}$$

Substituting (2)–(4) into (1) and solving for dP, we can derive the electricity price impacts as a function of the various policy changes. Let $\chi = -D'/\left(S_f'S_g'S_r' - D'(S_g'S_r' + S_f'S_r' + S_f'S_g')\right) > 0.$ Then we can define weights for source-specific policy changes as a function of the supply curve slopes of competing sources and χ, which determine the incidence of those changes: $\omega_r = \chi S_f' S_g'$, $\omega_f = \chi S_g' S_r'$, $\omega_g = \chi S_f' S_r'$, and $\omega_D = 1 - \omega_f - \omega_g - \omega_r$. Note that $0 < \omega_i < 1$, for all *i*.

The resulting price change can be expressed as a weighted average of the net tax and subsidy changes for fossil and renewable energy sources:

$$dP = \bar{\mu} dt - \omega_r ds - \omega_D db, \tag{5}$$

where $\bar{\mu} \equiv \left(\omega_f (m_f - a_f) + \omega_g (m_g - a_g) + \omega_r (m_r - a_r)\right)$ is a weighted average of the embodied emissions liability for generation, in which the slopes of the supply curves weight the individual per-unit compliance obligations.[8] For sensible price responses to allowance cost changes, we make the following assumption restricting the policy design:

Assumption 1. Allowance allocations for each policy *j* are such that $\bar{\mu}_j > 0$ (the weighted net emissions rate is positive) and $dP / dt > 0$ is assured.

From (5), we see that the wholesale price of electricity is increasing in the emissions tax *t*, assuming that the weighted average benchmarks are lower than the average emission rates. It is decreasing in the electricity consumption tax *b*, as well as in the renewable energy subsidy, *s*. The net effect of changes in multiple policy variables on the price of electricity depends on the relative weights, which in turn are functions of the slopes of all the supply curves, as well as electricity demand.

Emissions trading systems that embrace fossil fuels but do not cover renewables have stronger price effects, the steeper the renewable energy supply and the flatter the fossil energy supply; these cases imply less flexibility to switch toward renewables. The opposite is true for policies targeting the renewables sector: price impacts are stronger when the renewable energy supply curve is flatter or the fossil energy supply curves are steeper (see also Fischer 2010).

Substituting (5) back into (2)–(4), we solve for the impacts on electricity supplies:

$$df = \left(\left(\bar{\mu} - (m_f - a_f)\right) dt - \omega_r ds - \omega_D db\right) / S_f' \tag{6}$$

$$dg = \left(\left(\bar{\mu} - (m_g - a_g)\right) dt - \omega_r ds - \omega_D db\right) / S_g'. \tag{7}$$

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[8] This follows the presentation in FP, now including the benchmarks.

$$dr = \left((\bar{\mu} + a_r) dt + (1 - \omega_r) ds - \omega_D db \right) / S_r' . \tag{8}$$

From equation (8), we see that renewables generation is increasing with higher subsidies to renewables and higher emissions prices (as long as $\bar{\mu} > -a_r$). From equations (6) and (7), we see that fossil energy sources are decreasing with increased support for renewables, which tend to displace fossil sources. Higher emissions prices also reduce production from the fossil source *i* if $m_i - a_i > \bar{\mu}$; that is, if its net emissions liability is higher than the average among fossil sources. From all three equations, we see that all energy sources are decreasing with higher taxes on electricity consumption in inverse proportion to the slope of their supply curve.

Since our model focuses on the fuel-switching options for reducing emissions, for emissions pricing to have sensible results, we assume that the higher-intensity fossil source (coal) is always relatively under-allocated: that is, it has a higher-than-average net emissions rate $(m_f - a_f > \bar{\mu})$, leaving it with a net emissions liability. On the other hand, the less intensive fossil source (natural gas, which emits CO_2 at about half the intensity of coal) may be relatively overallocated on net (i.e., $m_g - a_g < \bar{\mu}$), depending on the stringency of the emissions regulation and the treatment of renewable generation for compliance.

The above equations reveal the basic responses to the policy price levers (renewables subsidies or electricity consumption taxes). In reality (and as discussed below), one or more of these levers may be endogenous.

Notably, we have the additional policy constraint that total emissions $(E = m_f f + m_g g)$ cannot exceed the total allowance allocation:

$$m_f f + m_g g \le a_f f + a_g g + a_r r + A \tag{9}$$

We will restrict ourselves to binding regulations, implying that in equilibrium this constraint will hold with equality. Totally differentiating this market-clearing requirement yields the requirement that the total change in emissions must equal the total change in allowance allocation:

$$m_f df + m_g dg = a_f df + a_g dg + a_r dr + dA \tag{10}$$

With this additional equation, we can solve the system with the endogenous change in the emissions price, *dt*, needed to bring the total change in emissions into balance with the total allowance allocation. This response depends on the particular combination of ETS and overlapping policy. We consider several combinations below.

B. Overlaps between ETSs and a subsidy or tax

We focus on how outcomes differ depending on the magnitudes of the subsidy to renewable energy or the tax on electricity consumption that overlaps with the ETS. Specifically, we explore the implications of changes to a subsidy to renewable energy (*ds*) or to a tax on electricity consumption (*db*) in the presence of various ETSs.[9] We begin with exogenous changes in the tax or subsidy. In Section II.C, we then consider combination cases in which the tax and subsidy may be linked by a policy requirement. Examples of linkage arise when subsidies to renewables are funded by taxes on electricity consumption, either explicitly (as in with many feed-in tariff programs) or implicitly (as with renewable portfolio standards, which require energy suppliers to purchase renewable energy credits in proportion to their energy sales (Fischer, 2010). Electricity consumption taxes may also be applied to fund transmission infrastructure or energy efficiency programs. We are particularly interested in the case where they are levied as an indirect tax on the embodied emissions associated with generation. The results that follow in this section provide the building blocks for analyzing the effects of those combinations.

1. Cap and trade

We start with the case in which the ETS takes the form of cap and trade. Under a fixed cap, $a_r = a_g = a_f = dA = 0.$ As a result, emissions are fixed $(dE^{\text{CAT}} = 0)$.[10] What does respond is the emissions price. Solving the system, we get

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[9] The change could be relative to an initial value of zero (which indicates the impact of the introduction of the subsidy or tax) or from an initially positive value. Although the focus is on marginal changes, the impact of a "large" change to the subsidy or tax can be viewed as the integral of successive marginal changes.

[10] In this paper, we make the assumption that the subsidy does not apply to sectors that are not included in the emissions cap. Furthermore, although the emissions level determined by the emissions cap remains unaffected, there may still be an impact on overall emissions due to emissions leakage into sectors that are not covered. To evaluate this effect, a general equilibrium model like the one in secton III is necessary.

$$dt^{\mathrm{CAT}} = (\Psi^{\mathrm{CAT}})^{-1}(S'_g m_f + S'_f m_g)\left(D'ds - S'_r db\right) \tag{11}$$

where $\Psi^{\mathrm{CAT}} = S'_r\left(S'_f m_g{}^2 + S'_g m_f{}^2\right) - D'\left(S'_g m_f^2 + S'_r(m_f - m_g)^2 + S'_f m_g{}^2\right) > 0$. Ceteris paribus, $dt^{CAT}/ds < 0$ and $dt^{CAT}/db < 0$: increasing support to renewables or increased incentives to reduce demand via a tax on electricity will push down the emissions price.

The effect on overall output is

$$dY^{\mathrm{CAT}} = (\Psi^{\mathrm{CAT}})^{-1}\left((S'_g m_f + S'_f m_g)ds - \left(S'_g m_f^2 + S'_r(m_f - m_g)^2 + S'_f m_g^2\right)db\right) \tag{12}$$

Ceteris paribus, $dY^{CAT}/ds > 0$ and $dY^{CAT}/db < 0$. Overall output rises with a higher renewables subsidy, which directly lowers renewable energy costs and indirectly lowers the compliance cost burden on fossil sources, as allowance prices decline. However, the shift towards meeting the cap with more renewables and less conservation entails a loss in efficiency (in the absence of other market failures).

Furthermore, we see the result of Böhringer and Rosendahl (2010) that the subsidy-induced fall in the allowance price will allow the relatively emissions-intensive source to increase its output, at the expense of the less emissions-intensive fossil source. Since emissions only come from the two fossil sources, and total emissions are given by the cap, if generation from one falls, generation by the other must rise $(m_f df + m_g dg = 0)$. The emissions-intensive source thus has a negative relationship with the carbon price, while the less intensive source has a positive relationship:

$$\frac{df^{\mathrm{CAT}}/ds}{dt^{\mathrm{CAT}}/ds} = \frac{df^{\mathrm{CAT}}/db}{dt^{\mathrm{CAT}}/db} = \frac{m_g(m_g - m_f)}{S'_g m_f + S'_f m_g} < 0; \quad \frac{dg^{\mathrm{CAT}}/ds}{dt^{\mathrm{CAT}}/ds} = \frac{dg^{\mathrm{CAT}}/db}{dt^{\mathrm{CAT}}/db} = \frac{m_f(m_f - m_g)}{S'_g m_f + S'_f m_g} > 0$$

Since both policy changes lower the equilibrium carbon price, both cause the more carbon-intensive source to expand, while the less carbon-intensive source contracts.

Renewables, of course, are helped to a greater extent by the subsidy than they are harmed by the fall in electricity and emissions prices:

$$\frac{dr^{\mathrm{CAT}}}{ds} = \left(S'_g m_f{}^2 + S'_f m_g{}^2 - D'(m_f - m_g)^2\right)/\Psi^{\mathrm{CAT}} > 0 \tag{13}$$

The sign of the change is clearly positive, since supply curves are upward sloping and demand is downward sloping, and the squared terms and denominator are positive. Indeed, if renewables did not expand, there would be no crowding out to cause the price changes.

On the other hand, a tax on electricity tends to crowd out renewables as well as fossil sources on average:

$$\frac{dr^{\mathrm{CAT}}}{db} = -\left(S_g' m_f{}^2 + S_f' m_g{}^2\right) / \Psi^{\mathrm{CAT}} < 0$$

We summarize these results in the following proposition:

Proposition 1: *In the presence of a CAT system, a higher renewable energy subsidy implies a lower emissions price and greater output of both renewables and the higher-emitting source, as well as higher overall output. A higher electricity consumption tax implies a lower emissions price and less total output.*

2. Uniform sector-wide performance standards

With uniform sector-wide performance standards (USPS), the goal set by the regulation is to meet an average emissions intensity for all generators. Uniformity of the benchmark means that $a_f = a_g = a_r = a.$ The policy essentially combines a price on emissions (*t*) with an implicit subsidy to output (*ta*), which incentivizes production equally for all non-baseload sources (Fischer and Newell 2008).

Proposition 2: *Ceteris paribus, increasing a renewable energy subsidy in the presence of a USPS will lower the emissions price and increase both output and emissions.*

Proof. Solving our set of equations using this form of allowance allocation, and setting *db* = 0, we find that

$$\frac{dt^{\mathrm{USPS}}}{ds} = \left(-aS_f' S_g' + (S_g' m_f + S_f' m_g) D'\right) / \Psi^{\mathrm{USPS}} < 0 \tag{14}$$

$$\frac{dY^{\mathrm{UTPS}}}{ds} = \mathrm{M}^{\mathrm{USPS}} / \Psi^{\mathrm{USPS}} > 0 \tag{15}$$

where

$\Psi^{\text{USPS}} = S_r' S_f' (a - m_g)^2 + S_r' S_g' (a - m_f)^2 + S_f' S_g' a^2 - D'\left(S_g' m_f{}^2 + S_r'(m_f - m_g)^2 + S_f' m_g{}^2\right) > 0$ and $\mathrm{M} = \left(S_g' m_f (m_f - a_f) + S_f' m_g (m_g - a_g)\right).$ The proof for the numerator being positive follows from $\bar{\mu}^{\text{USPS}} = \chi\left(S_g' S_r'(m_f - a) + S_f' S_r'(m_g - a) + S_g' S_f' (m_r - a)\right) > 0$, which implies $S_g'(m_f - a) + S_f'(m_g - a) > aS_g' S_f' / S_r'$. Thus $\mathrm{M}^{\text{USPS}} = \left(S_g' m_f (m_f - a) + S_f' m_g (m_g - a)\right) > m_g \left(S_g'(m_f - a) + S_f'(m_g - a)\right) > m_g a S_g' S_f' / S_r' > 0.$ Emissions increase in proportion to output and the benchmark: $dE^{\text{USPS}} / ds = a \cdot dY^{\text{USPS}} / ds > 0.$ □

Under the USPS, total emissions are (by definition) proportional to output. In the presence of the USPS, adding a subsidy to renewables generation has three effects: i) it lowers costs for renewable supply directly; ii) by expanding production of a source with emissions below the benchmark, it depresses the emissions price, lowering costs for fossil energy sources; and iii) it depresses the value of the implicit output subsidy, which is tied to the emissions price. The first two factors would tend to expand overall production, but the third factor puts a drag on production.

With a USPS, the more emissions-intensive (under-allocated) fossil source gains unequivocally from an increase in renewables support, while the less-intensive source necessarily loses market if $a > m_g$:

$$\frac{df^{\text{USPS}}}{ds} = \left(S_g' a(m_f - a) - D' m_g (m_f - m_g)\right) / \Psi^{\text{USPS}} > 0;$$
$$\frac{dg^{\text{USPS}}}{ds} = -\left(S_f' a(a - m_g) - D' m_f (m_f - m_g)\right) / \Psi^{\text{USPS}}$$

For coal-fired generation, the fall in the carbon price lowers its net costs more than the fall in the price it receives for electricity. Natural gas-fired generation loses not only from lower prices but, to the extent it is overallocated, from lower values for its net allowance sales as well. As a result, the additional emissions from more coal-fired generation can outweigh the additional emissions savings from less gas-fired generation. If natural gas sources are also under-allocated, then the carbon price fall can help them expand as well, leading naturally to higher total emissions.

In contrast with a renewables subsidy, a tax on electricity consumption directly affects both renewable and fossil energy sources. From Equation (5), we know that consumption taxes reduce demand and depress the electricity price for all sources, causing each to decrease their supply in inverse proportion to the slope of their supply curve (by $db(\omega_D / S_i')$). As a result, demand for emission allowances also falls, and we can demonstrate the following:

Proposition 3: *Ceteris paribus, under a USPS, increasing an electricity consumption tax will cause overall output, emissions, and the emissions price to fall.*

Proof. Solving the system of equations, we get

$$\frac{dt^{\text{USPS}}}{db} = -\bar{\mu}^{\text{USPS}} / \chi / \Psi^{\text{USPS}} < 0 \tag{16}$$

$$\frac{dY^{\text{USPS}}}{db} = -\left(S_g' m_f^2 + S_r'(m_f - m_g) + S_f' m_g^2\right) / \Psi^{\text{USPS}} < 0 \tag{17}$$

Since emissions are simply proportional to demand, any reduction in demand will lower emissions. □

Although an electricity consumption tax does not directly distinguish among sources, the indirect effects on the emissions price do discriminate. We find that an increase in the tax necessarily decreases total output, as well as production by the *less* intensive emitting source. If that source is under-allocated ($m_g > a$), renewable energy generation also falls, but the dirtiest generation may not (whereas the opposite is true if the less intensive source is over-allocated):

$$\frac{df^{\text{USPS}}}{db} = \left(-S_g' a m_f + S_r'(m_g - a)(m_f - m_g)\right) / \Psi^{\text{UTPS}}$$

$$\frac{dg^{\text{USPS}}}{db} = \left(-S_f' a m_f - S_r'(m_f - a)(m_f - m_g)\right) / \Psi^{\text{UTPS}} < 0$$

$$\frac{dr^{\text{USPS}}}{db} = \left(-S_g' m_f (m_f - a) - S_g' m_g (m_g - a)\right) / \Psi^{\text{UTPS}}$$

In other words, two of the three types of sources reduce generation in response to the tax, while the third expands some of its share of the shrinking market; the dirtier source benefits if the emissions market is tight and both emitting sources are net buyers of allowances, whereas renewables benefit if the emissions market is looser and both it and the less intensive emitting source are net sellers of allowances.

3. Emitter performance standards

Under emitter performance standards, the benchmark standards and compliance requirements are applied only to emitting sources. Since clean sources are thus excluded from the regulation, they receive no benchmark allocation value and thus no corresponding output subsidy.

We can distinguish two categories of EPSs. A uniform EPS (UEPS) applies the same benchmark to all emitting sources (and only to emitting sources). A differentiated EPS (DEPS) applies different benchmarks to the emitting sources, distinguishing, for example, coal-fired from gas-fired generation, or blast furnaces from electric arc furnaces in steelmaking. Canada and China have implemented DEPSs. In those countries, more generous benchmarks are given to higher emitting sources: i.e., $a_f > a_g > a_r = 0$. In Canada, after a transition period, the intent is for this additional differentiation across electricity generators to be phased out, shifting from a DEPS to a UEPS.

As previously mentioned, the present analysis focuses on the incentives for fuel switching and conservation, rather than fuel efficiency or direct abatement options. Consequently, for an EPS policy to have a meaningful effect on reducing emissions, the policy must be designed such that the relatively emissions-intensive source is under-allocated, while the less intensive source is overallocated $(m_f > a_f \geq a_g > m_g)$. The following results apply to any EPS, recognizing that the main distinction between a UEPS and DEPS is that the high-intensity fossil sources receive a more generous allocation under a DEPS than under a UEPS, which limits the reductions that can be achieved relative to the case under the UEPS.

Proposition 4: *In the presence of an EPS that excludes clean sources, increasing a subsidy to renewable energy will lower both the emissions price and emissions while raising output.*

Proof. Let $\Delta_f = m_f - a_f > 0$ and $\Delta_g = a_g - m_g > 0$. Assuming that $a_r = 0$ and defining

$\Psi^{\text{EPS}} = S_r' S_f' \Delta_g^2 + S_r' S_g' \Delta_f^2 - D'\left(S_g' \Delta_f^2 + S_r'(\Delta_f + \Delta_g)^2 + S_f' \Delta_g^2\right) > 0$, we can show that

$$\frac{dt^{\text{EPS}}}{ds} = \left(S_g' \Delta_f - S_f' \Delta_g\right) D' / \Psi^{\text{EPS}} = \frac{\overline{\mu}^{\text{EPS}}}{\chi S_r'} D' / \Psi^{\text{EPS}} < 0 \tag{18}$$

$$\frac{dE^{\mathrm{EPS}}}{ds} = \left(\Delta_f + \Delta_g\right)\left(m_g \Delta_f + m_f \Delta_g\right) D' / \Psi^{\mathrm{EPS}} < 0 \tag{19}$$

$$\frac{dY^{\mathrm{EPS}}}{ds} = \left(S'_g \Delta_f^2 + S'_f \Delta_g^2\right) / \Psi^{\mathrm{EPS}} > 0 \tag{20}$$

where $\left(S'_g \Delta_f - S'_f \Delta_g\right) \chi S'_r = \bar{\mu}^{\mathrm{EPS}} \equiv \left(\omega_f (m_f - a_f) + \omega_g (m_g - a_g)\right) > 0$ by Assumption 1 for sensible energy price responses to emissions price changes. □

As indicated by equation (19) above, supplementing an EPS with a higher subsidy for renewables lowers emissions. In a sense, the subsidy to renewables corrects the distortion of that source's under-allocation relative to fossil sources. Expanding renewables helps displace fossil energy sources, which reduces the number of allowances allocated and thus emissions. In fact, both types of emitting sources are crowded out, which could not happen under a CAT and was not certain under a USPS:

$$\frac{df^{\mathrm{EPS}}}{ds} = \Delta_f \left(\Delta_f + \Delta_g\right) D' / \Psi^{\mathrm{EPS}} < 0; \quad \frac{dg^{\mathrm{EPS}}}{ds} = \Delta_g \left(\Delta_f + \Delta_g\right) D' / \Psi^{\mathrm{EPS}} < 0 \tag{21}$$

Since total output rises, the increase in renewables is obviously greater than the decrease in emitting sources.

The overall effects of an electricity consumption tax increase are similar under a differentiated and uniform TPS, but now it is clear that the emissions price adjustment does not prevent all sources from contracting.

Proposition 5: *Ceteris paribus, under an EPS, increasing an electricity consumption tax will cause a decline in output from all sources, along with a decline in emissions and the emissions price.*

Proof. Under an EPS,

$$\frac{dt^{\mathrm{EPS}}}{db} = -\bar{\mu}^{\mathrm{EPS}} / \chi / \Psi^{\mathrm{EPS}} < 0 \tag{22}$$

$$\frac{dE^{\mathrm{EPS}}}{db} = -\left(\Delta_f + \Delta_g\right)\left(m_g \Delta_f + m_f \Delta_g\right) S'_r / \Psi^{\mathrm{EPS}} < 0 \tag{23}$$

$$\frac{dY^{\mathrm{EPS}}}{db} = -\left(S'_g \Delta_f^2 + S'_f \Delta_g^2 + S'_r (\Delta_f^2 + \Delta_g^2)\right) / \Psi^{\mathrm{EPS}} < 0 \tag{24}$$

$$\frac{df^{\text{EPS}}}{db}=-\frac{\Delta_g\left(\Delta_f+\Delta_g\right)S_r'}{\Psi^{\text{EPS}}}<0;\quad \frac{dg^{\text{EPS}}}{db}=-\frac{\Delta_g\left(\Delta_f+\Delta_g\right)S_r'}{\Psi^{\text{EPS}}}<0;\quad \frac{dr^{\text{EPS}}}{db}=-\frac{\Delta_g^2S_f'+\Delta_f^2S_g'}{\Psi^{\text{EPS}}}<0. \qquad (25)$$

Since all sources contract to some extent, emitting sources overall receive a lower allocation. □

Note that an important distinction between a UEPS and a DEPS is the size of Δ_f and Δ_g. With a DEPS, both are smaller, since benchmarks are more closely aligned with emission intensities, which also means that Ψ^{EPS} is smaller. With smaller numerators and denominators, it is not clear from the theory whether that differentiation amplifies emissions and price effects.

4. Summary of insights from theory

Table 2a summarizes the effects of the various policy overlaps on the three variables of interest: the emissions price, sector emissions, and sector output.

Table 2a. Summary from Theory: Effects of Overlapping Exogenous Subsidies and Taxes

Overlapping Policy	Existing ETS	Allowance Price Change	Emissions Change	Output Change
Renewables Subsidy	CAT	−	0	+
	USPS	−	+	+
	EPS	−	−	+
Electricity Consumption Tax	CAT	−	0	−
	USPS	−	−	−
	EPS	−	−	−

Note: CAT – cap and trade; USPS – uniform sector-wide tradable performance standard, EPS – emitter performance standard. In the cases shown here, the changes in the subsidy and tax rates are regarded as exogenous rather than linked to each other.

The theory reaffirms results from prior studies that consider overlaps with cap and trade, while also offering new results for overlaps with other ETSs. Specifically, policies that drive additional renewable energy or conservation cause allowance prices to fall, not only when the ETS is CAT but also when it is a TPS. Under all of the forms of ETS considered, total sector output increases with overlapping policies like renewable subsidies that reduce supply costs but falls with policies like consumption taxes that increase product costs.

However, the effect of overlapping policies on emissions—the main target of ETS regulations—depends critically on the type of ETS. Under CAT, aggregate emissions are determined by a fixed cap; overlapping policies do not change total emissions. But when emissions are regulated by a TPS – a rate-based ETS -- the results depend on both the particular type of TPS (USPS or ETS) and the type of overlap (renewables subsidy or tax on electricity consumption).

When a TPS overlaps with an exogenous subsidy to renewables, the overlapping subsidy leads to higher emissions when the TPS is a USPS: both the subsidy and the ensuing lower emissions prices lower production costs, allowing an expansion of generation and thereby higher emissions. In contrast, when the TPS is an EPS (under which renewables are not allocated allowances), an overlapping subsidy only changes the overall allocation of emission allowances to the extent it changes the output of covered sources; by crowding out production by emitting sources, the allocations and emissions of these sources fall. When a TPS overlaps with an exogenous tax on electricity consumption, there is less demand for output from all sources, reducing allowance allocations and thus emissions. The direct effect of the tax increase dominates any indirect cost savings from lower allowance prices, whether the TPS takes the form of a USPS or EPS. This stands in contrast to the CAT, where the allowance price change must fully absorb the change in demand for allowances.

C. Overlaps with linked electricity consumption taxes

Up to now, we have examined the interaction of an ETS with exogenously implemented overlapping subsidies or taxes. Now we extend the analysis to consider situations in which the electricity consumption tax is endogenously determined. This additional focus is policy-relevant: as part of climate policy, taxes on electricity are often linked to the emissions or to renewables policies rather than introduced as independent rates. We concentrate on two main examples. First, we consider a case where the ETS policy includes a tax on electricity based on the emissions embodied in electricity consumption. Second, we consider a case where the emissions policy includes an electricity tax surcharge designed to finance the renewables support mechanism.

The first case—involving a tax related to the value of emissions embodied in electricity consumption —is commonly proposed to address issues of incomplete price pass-through. The linkage arises when that value is determined by the prevailing ETS price. Incomplete price pass-through may occur, for example, due to rigidities in electricity markets with rate regulation, or due to the output subsidies implicit in benchmark allocations, which often aim to address competition with unregulated goods (Neuhoff et al. 2016). California prices embodied emissions in imported electricity. The Republic of Korea's ETS and China's regional ETS pilots both cover the indirect emissions from electricity consumption (IEA, 2020; ICAP, 2023).[11] A planned feature of the Chinese ETS is an implicit tax on the emissions embodied in electricity through a requirement that covered industrial emitters surrender emission allowances not only for their direct emissions but also for the indirect (embodied) from power generation.

A second case of linkage can arise from a requirement of revenue-neutrality.[12] As previously mentioned, many countries—including China—have committed goals for the expansion of renewable energy, and subsidies to renewables are frequently funded by earmarked taxes on electricity consumption, either explicitly through ratepayer-financed feed-in tariffs or implicitly through renewable portfolio standards. In such cases, revenue-neutrality requires the electricity consumption tax rate to equal the renewables subsidy multiplied by the renewable market share.[13]

1. Electricity tax linked to emissions embodied in electricity consumed

When linked with an ETS, a tax on the emissions embodied in the consumption of the regulated good (in this case, electricity) is the product of two endogenous variables: 1) the emissions price from the ETS, and 2) the emissions intensity of electricity production, as influenced by the regulation. In our terminology, db is the (now endogenous) tax on electricity

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[11] Korea's ETS is a mass-based system with indirect emissions from electricity consumption covered. Similarly, China's ETS pilot in Chongqing follows a mass-based approach that also accounts for indirect emissions from electricity consumption. Consequently, we have examined a CAT system linked with an embodied emissions tax in both theoretical and numerical applications, as this reflects certain policy practices in reality.

[12] Many emissions-reduction policies are effectively a combination of policy instruments (Fischer and Newell 2008).

[13] A renewable portfolio standard is functionally equivalent to the combination of a subsidy to renewables (the value of a renewable energy credit) and a tax on consumption (the credit value multiplied by the standard). See, for example, Goulder, Hafstead, and Williams (2016).

consumption, equal to the per-unit embodied emissions cost. We will use the suffix “-2” to identify the cases involving embodied emissions taxes. Indirect emissions from electricity are commonly referred to as Scope 2 emissions, in contrast to Scope 1 direct emissions and Scope 3 other indirect emissions.

Suppose electricity consumers face an emissions price $b = t\bar{a}$, where $\bar{a} = E / Y = (a_f f + a_g g + a_r r + A) / Y$ is the average emissions per unit of electricity, equal to the average per unit allocation. Then $db = (dt)\bar{a} + (d\bar{a})t$. The change in embodied emissions intensity with respect to changes in the source variables is

$$\begin{aligned} d\bar{a} &= \frac{\overbrace{a_g dg + a_f df + a_r dr}^{dE}}{Y} - \frac{EdY}{Y^2} \\ &= \frac{(a_g - \bar{a})dg + (a_f - \bar{a})df + (a_r - \bar{a})dr}{Y} \end{aligned} \tag{26}$$

The equilibrium change in embodied emissions depends on the type of ETS. Under CAT, average intensity falls with output: $d\bar{a}_{\text{CAT}} = -\bar{a}dY / Y$. With a USPS, average intensity is fixed by design: $d\bar{a}_{\text{USPS}} = 0$. With an EPS, the change in the average emissions rate depends on the change in the composition of output: $d\bar{a}_{\text{EPS}} = \big((a_g - \bar{a})dg + (a_f - \bar{a})df - \bar{a}dr\big) / Y$.

The following propositions explain the intuition of the effects of changes in an overlapping subsidy to renewables in a context with an embodied emissions tax linked to the ETS price. For clear and coherent results, we restrict the range of the embodied emissions tax such that $t\bar{a} < -D'Y$. This restriction is akin to assuming that, with linear demand, a price equal to the embodied emissions charge would lie in the elastic portion of the demand curve.[14]

Proposition 6: *In a CAT system with a linked embodied emissions tax, increasing a subsidy to renewable energy raises output and lowers emissions prices.*

Proof. From Proposition 1, a renewable subsidy increases output, which lowers the average emissions intensity, given that total emissions are fixed under a CAT. It also lowers the emissions price. These effects in turn lower the embodied emissions tax $(db / ds = (A / Y)dt / ds - t(A / Y)(dY / ds) / Y) < 0)$, and a lower electricity consumption tax amplifies

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[14] This restriction is akin to avoiding a Laffer-Curve-type of response.

the output increase, while only partially attenuating the emissions price change. (A mathematical proof is provided in the appendix, available at http://www.nber.org/data-appendix/w33197.)□

Proposition 7: *In a USPS system with a linked embodied emissions tax, increasing a subsidy to renewable energy lowers emissions prices and raises both output and emissions.*

Proof. With a USPS, the embodied emissions tax change depends only on the emissions price effect of the additional intervention $(db = a \cdot dt)$. From Proposition 2, a higher renewable subsidy increases total output and lowers the emissions price, which implies a decrease in the linked consumption tax. From Proposition 3, a lower consumption tax amplifies the output increase. Since emissions are proportional to output, emissions rise. (Mathematical proof provided in the appendix.)□

In other words, while adding indirect emissions pricing to a USPS can reduce emissions, it makes the system more sensitive to other overlapping policies. For example, renewable subsidies become more environmentally counterproductive: with linked embodied emissions pricing, increasing a subsidy to renewables drives larger increases to output and emissions under USPS than without indirect emissions pricing.

Proposition 8: *In an EPS system with a linked embodied emissions tax, increasing a subsidy to renewable energy will lower the embodied emissions tax, lower total emissions, and allowance prices, and raise total output.*

Proof. With an EPS, the change in the electricity consumption tax has three drivers: the change in the emissions price, the change in emissions, and the change in output $(db = \bar{a}dt + t\left(dE - \bar{a}dY\right)/Y).$ From Proposition 4, an increase in the renewable subsidy puts downward pressure on both emissions and emissions prices and upward pressure on output. All of these drive down the embodied emissions tax. From Proposition 5, a reduction in the consumption tax puts upward pressure on output, as well as on emissions and emissions prices. Thus, the direct and indirect effects of an increase in the renewable subsidy align to expand output, but they push emissions and the emission price in opposite directions. The mathematical proof in the appendix) demonstrates that the first effects from the renewable subsidy dominate the indirect effects of the embodied emissions tax changes, at least when $t\bar{a} < -D'Y$.

2. Electricity-tax–funded renewables subsidy

Here we briefly consider the effect of changes in the renewable energy subsidy when the subsidy and tax are linked through the requirement that the subsidy be financed through a tax on electricity consumption. Many countries, including China, have committed to such financing of renewables subsidies.

With such linkage, we have $b = s \cdot r$, so $db = ds \cdot r + s \cdot dr.$ In this case, higher renewable subsidies raise revenue requirements and the needed electricity consumption tax rate. Using the results in Section II.B (Table 2a), we can infer the effects of *ds* and *db* on prices, output, and emissions. The results are in Table 2b below.

Both of these actions depress allowance prices across all policies. Therefore, an increase in an electricity-tax-funded renewable subsidy unambiguously lowers emissions prices, regardless of the ETS in play. This price decrease should be larger than if the electricity consumption tax were exogenously determined.

Regarding total output, ceteris paribus, a higher renewable subsidy raised output under all ETSs, while a higher consumption tax reduced it. These actions work in opposite directions, so the output impacts are ambiguous and depend on the size of the subsidy and the share of renewables in output. The question is whether the supply cost reduction from the renewable subsidy is more than offset by the consumer cost increase from the tax. Fischer (2010) demonstrated that renewable portfolio standards could increase or decrease retail electricity prices for consumers, depending on the relative slopes of the supply curves and the stringency of the policy. Therefore, it is possible that such a linked renewable energy policy could increase or decrease total output under any ETS scenario.[15]

Regarding emissions, the directions of the effects depend on the ETS type. As was the case with exogenous taxes and subsidies, emissions do not change when the ETS is in the form of CAT. With a USPS, emissions rise or fall in proportion to total output, so the impact of the linked subsidy is ambiguous in this case. However, both actions cause emissions to fall under an EPS; therefore, increasing an electricity consumption tax-funded renewable subsidy will drive down emissions when overlapping with an EPS.

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[15] For this reason, a mathematical treatment is not offered, as it does not yield unambigous results.

3. Summary of overlapping linked subsidies and taxes

Table 2b. Summary from Theory: Effects of An Increase in An Overlapping Policy

Overlapping Policy	Existing ETS	Allowance Price Change	Emissions Change	Output Change
Renewable Subsidy with Embodied Emissions Taxes	CAT-2	−	0	+
	USPS-2	−	+	+
	EPS-2	−	−	+
Renewable Subsidy Financed by Consumption Tax	CAT-T	−	0	+?–
	USPS-T	−	+?–	+?–
	EPS-T	–	–	+?–

Note: CAT - cap and trade; USPS - uniform sector-wide tradable performance standard, EPS - emitter performance standard.

Under each type of ETS, a sector consumption tax linked to embodied emissions costs affects the magnitude but not the direction of impacts from a change in an overlapping renewable subsidy. The renewable subsidy tends to expand output and drive down the emissions price, which serves to lessen the embodied emissions costs, further allowing output to expand. The consumption tax response has an attenuating impact on the emissions price but does not undo the direct effects.

By contrast, when the electricity consumption tax is used to fund renewable subsidy costs, an increase in the subsidy rate requires a higher tax. Both of these actions drive down the emissions price necessary to meet any of the ETS requirements. But they push output in different directions. In the case of the USPS, this means the effect on emissions is uncertain. By contrast, with an EPS, both actions drive down emissions.

D. Efficiency considerations

Our results have important implications for understanding the consequences of overlapping policies on the overall efficiency or cost-effectiveness of emissions trading.[16] When

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[16] Here we are measuring efficiency in terms of the costs of achieving given targets for emissions reductions. Thus it is synonymous with cost-effectiveness. A broader notion of efficiency would consider the environment-related benefits (avoided damages) as well as the costs from the reducitons. Such benefits are beyond the scope of this study. We simply note here that two policies that produce the same aggregate emissions reductions can yield different net benefits insofar as the environmental consequences from the reductions differ.

the only market failure is from the emissions-related externality, CAT is the most cost-effective, and adding renewable subsidies or electricity consumption taxes increases costs per ton of abatement. TPSs alone are less cost-effective, but overlapping policies have the potential to increase (or decrease) cost-effectiveness,[17] and in some cases, a TPS can emerge as more efficient than a CAT system with the same overlaps.

For example, with a uniform sector-wide TPS (the USPS) achieving the same emissions outcomes as CAT, in the absence of overlaps, the emissions price will be too high and the electricity price too low in terms of efficiency. An overlapping electricity tax (a tax on output) can help undo the distortion from the implicit subsidy stemming from the policy's output-based allocation. In contrast, an overlapping renewables subsidy expands the USPS's efficiency handicap by further depressing output prices and putting upward pressure on emissions and requiring more stringent intensity standards to compensate.

An EPS, by virtue of applying the performance standard only to emitting sources, introduces inefficiencies by subsidizing the output of emitting sources to the exclusion of clean sources. Relative to a uniform EPS (UEPS), a differentiated EPS (DEPS) adds to inefficiency by offering different benchmarks (and associated subsidies) to emitting sources that depend on their emissions intensities. For a given emissions target, the allowance price will have to be even higher to achieve comparable overall incentives to reduce emissions. Linking the electricity tax to the embodied emissions in electricity consumption can offset some of the output subsidies *on average*, thereby helping to improve efficiency. However, it does not undo the inefficiency from the benchmark differentiation. A renewables subsidy can make up for the lack of comparable benchmark allocation to renewables under a DEPS, promoting efficiency by in effect making the standard more uniform.

These efficiency considerations provide a springboard for the more detailed treatment and quantitative results from the numerical model. The numerical model has an explicit treatment of production costs, which yields quantitative results in terms of cost-effectiveness. It also considers an additional emission-reduction channel beyond the fuel-switching and demand-reduction channels captured by the theoretical model: this is the potential of covered firms to reduce emissions intensities through changes in production methods. It also addresses general

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[17] See Braathen (2007) and Fischer, Huebler and Schenker (2019).

equilibrium interactions across sectors. These additional channels can be expected to influence the quantitative outcomes but do not yield outcomes that differ qualitatively from the main findings obtained in this section. As part of a sensitivity analysis (detailed in the appendix), we identify the relative significance of the various channels mentioned here.

III. Results from numerical simulations

To understand the quantitative importance of ETS design and the role of overlapping policies, we conduct numerical simulations using a general equilibrium model applied to China. The evolving Chinese national ETS is a DEPS with several proposed overlaps, including a price on indirect CO_2 emissions arising from electricity consumption for certain industrial sectors and mandates for renewable energy shares. The numerical model allows us to explore how policy outcomes depend on the specific design of China's ETS and the overlapping policies.

A. The context: China's ETS and other policies

China's announced climate goals are to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060. The national ETS, introduced in 2021, is expected to contribute importantly to meeting those goals.

In its current phase, the system covers the electricity sector, which is responsible for over 40 percent of China's CO_2 emissions. Coverage is scheduled to expand to other sectors in several phases and eventually include most of the significant energy-intensive industries. The second phase is likely to begin sometime in 2024, when the system's coverage will expand to include the cement and aluminum sectors, and possibly the iron and steel sector as well. These three sectors currently account for about two-thirds of China's CO_2 emissions. One or more further phases are expected, during which the system will expand to cover other emission-intensive sectors, including pulp and paper, other non-metal products, other non-ferrous metals, chemicals, and refined petroleum. At that point, the system would likely account for at least 65 percent of China's CO_2 emissions.

China's emissions trading system employs different benchmarks for different kinds of covered entities, both across and within sectors. Within the electricity sector, there are three benchmarks for different categories of coal-fired power plants and one for gas-fired power plants. These plants receive free allowances equal to the product of their electricity generation and the corresponding benchmarks. Renewable electricity is not covered: it receives no free allowances. Thus, the Chinese ETS is a DEPS under our terminology.

In phases 2 and 3, when the system expands to industrial sectors, the non-electricity sectors likely to be covered will be required to surrender allowances not only for their own direct emissions but also for the indirect emissions associated with the electricity used by these sectors, following the precedence set by China's pilot ETSs (Zhang *et al.*, 2021). If this requirement applies, the free allowance allocation given to these industrial sectors via their own benchmarks will also be adjusted to reflect these indirect emissions requirements. As mentioned, this pricing of indirect emissions functions as a tax on electricity consumption for which the value is tied to the prevailing emissions price and the average emissions intensity of electricity. This additional compliance liability has the effect of partially offsetting the implicit output subsidy inherent in China's tradable performance standards for the electricity sector. The industrial consumers facing the charge on indirect emissions in electricity could be expected to consume roughly 10 percent and 25 percent of total electricity in Phase 2 and Phase 3, respectively.

China has to date been relying on subsidies to encourage the development of renewable energy. Before 2017, China deployed feed-in tariffs (FIT) to promote the development of wind and solar electricity. The FIT scheme offered a 20-year contract to eligible projects, featuring fixed FIT rates determined by the specific renewable technology, resource availability at the project site, and the year of plant construction. In keeping with the trend of cost decrease of renewable electricity generation, China has continuously lowered its FIT rates since 2014 and phased out FIT subsidies from the central government for new wind and solar projects by the end of 2020 (China, NDRC, 2021b). The National Development and Reform Commission (NDRC) has announced that the central government will discontinue direct production subsidies for new solar and wind power plants that are approved after 2021.

In 2019, China removed the FIT scheme. In its place, it introduced an RPS to promote sustainable development and better integration of renewables (NDRC and NEA, 2019). The RPS can be viewed as the major instrument to support the continued development of renewables in China, and thus it represents the most important policy with which China's ETS overlaps. The plan includes a provision for green electricity trading, Provincial governments are required to purchase enough renewable electricity to meet minimum targets for the share of renewable electricity in total electricity consumption for individual provinces (NDRC, 2023). Obligated parties can fulfill the targets by generating their own renewable electricity, by a bilateral agreement with those exceeding their RPS quota, or by buying green power through Green Power Trading or Green Certificates Trading. As discussed in the theory section above, this RPS is equivalent to an electricity-consumption-tax-funded subsidy, in which the subsidy rates are endogenously determined by the renewable share targets under TPS.

B. Numerical model

To evaluate China's nationwide ETS, we employ a multi-sector, multi-period general equilibrium model. The model is adapted from the version documented in Goulder *et al.* (2023). Thirty-one production sectors in China's economy are distinguished. In each sector (or subsector, as applicable), a representative firm employs inputs of primary factors (capital, labor, and natural resources) along with intermediate inputs (energy and material goods) to produce goods for the domestic market and export. A representative household earns income from returns to the factors of production and devotes that income to consumption, savings and transfers to the government. The government uses the transfers for government consumption and public savings. Private and public savings finance investment. The final demand for goods and services consists of household consumption demand, public and private investment demand, and the government's demand for goods and services. The model incorporates emissions allowance trading. For each year in the interval 2020 through 2035, it solves for the equilibrium factor prices and allowance prices as well as the prices of all produced goods. Details on the model's structure and parameters are provided in the appendix.

The model has several features that make it especially suitable for this study. It has considerable flexibility to examine CAT and various types of TPSs and the interactions between these systems and various overlapping policies. Its treatment of heterogeneous fuels and technologies enables it to capture the fuel-switching options under CAT and TPS systems. The electricity sector in the model distinguishes nine coal-fired generation technologies, two gas-fired generation technologies, two renewable generation technologies, and two baseload technologies (hydropower and nuclear power).

Additional features of the model enable it to address dimensions not captured by the theoretical model. In particular, its multi-period structure allows it to examine how impacts evolve with changes in coverage and policy stringency. Its general equilibrium framework enables it to consider the impacts of CAT and various types of tradable performance standards not only in the covered industries but in other industries as well. The incorporation of trade responses also allows it to consider changes in imports and exports and the corresponding emission leakage associated with these changes.[18]

C. Cases

Our numerical simulations consider a range of ETSs and overlapping policy scenarios. Building on the preceding insights, we define the following scenarios that differ according to the type of ETS in place—CAT, USPS, UEPS, and DEPS—and the policy or policies with which the ETS overlaps. We consider scenarios where these overlapping policies are implemented individually or in combination. These overlapping policy settings are summarized in Table 3. The labels R and S refer to overlapping RPSs and subsidies. The labels “2” and “N” respectively refer to scenarios with or without Scope 2 emissions pricing of electricity. NO indicates no overlaps.

The DEPS-R2 policy most closely approximates China’s actual policy environment, resulting in economy-wide emissions reductions of 7 percent, 8 percent, and 20 percent in the first, second, and third phases, respectively. For comparability, in the USPS and UEPS cases, relative benchmarks for fossil electricity versus non-fossil electricity are determined by the weighted average benchmarks under the DEPS, but the absolute benchmarks in each period across scenarios are scaled so that the resulting emissions in each year equals that of DEPS-R2.

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[18] Relative to the model in Goulder et al. (2023), this paper’s model incorporates some simplifications to permit a closer match with the theoretical model. It ignores pre-existing taxes on labor and capital and thus it disregards some second-best issues. Pre-existing distortions offer some justification for output-based rebating (Fischer and Fox 2011; Fischer and Springborn 2011); we reserve these aspects for future research. It also disregards some pre-existing regulations and associated distortions in the electricity sector. Historically, China’s electricity prices and supplies have faced significant government regulation. However, the system has been going through rapid reform in recent decades. Currently, about half of the electricity generated in China faces market prices. The nation aims to go further and achieve a fully liberalized electricity market system before 2025 (NDRC and NEA, 2021). Correspondingly, the numerical model treats electricity prices as market-determined. Also, the model includes a relatively simple treatment of capital dynamics, representing the real investment as fixed shares of gross domestic product.

China's stated policy overlaps ("R2") include the RPS as the renewable promoting policy and the scope-2 indirect emission pricing (IEP) for the ETS-covered sectors. In the model, the RPS policy is an endogenous electricity-consumption-tax-funded renewable subsidy, where the rates fulfill the projected RPS targets each year. The RPS target shares for non-hydro renewable electricity at the national level in 2025 and 2030 are drawn from NEA's consultation draft (NEA, 2021). The 2035 target is projected assuming consistent annual growth rates between 2030 and 2035 using linear trends.

Table 3. Overlapping Policies Considered

Overlapping Policy Cases	Renewable Support	Electricity Taxes
NO	None	None
R2	RPS	RPS+ IEP
RN	RPS	RPS
S2	IRS	IEP
SN	IRS	None
N2	None	IEP

Notes: i) Each overlapping policy case can pair with each of the four ETS types, indicated by a hyphen between the ETS type and the overlapping policy case. ii) NO: No overlaps. R: overlapping RPS set according to projected national targets each year. S: Independent renewable subsidy (IRS) set to meet projected RPS targets each year. 2: indirect emissions pricing (IEP) applied to the electricity consumption of ETS-covered industrial sectors.

Alternative overlapping cases reveal how different elements in the stated policy overlap R2 affect the abatement costs. The RN scenario simply removes the IEP from R2. The S scenarios remove the implicit electricity taxes on all electricity consumers by replacing the RPS scheme with an independent renewable subsidy (IRS), funded by general revenues, that achieves the national renewable share target. S2 would retain the IEP obligation, while SN eliminates it. N2 has no renewable support but retains the IEP.[19]

All policies are compared to a reference case with no ETS, renewables subsidies, or electricity taxes. Throughout, the cost per ton of abatement is measured as the present value of the equivalent variation of household consumption in each phase, divided by the cumulative domestic economywide emissions reductions (relative to emissions in the reference) in that phase.

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[19] Some scenarios defined here for completeness are reported only in extended simulations in the appendix.

D. Simulation results

1. Effects of China's stated policies

Figure 1 presents the cost per ton of abatement in different phases of the DEPS and CAT, with (-R2) and without (-NO) the stated policy overlaps of RPS and IEP. The cost difference across all phases of DEPS-NO is 131 percent higher than CAT-NO. However, in the presence of the stated overlaps, the cost of DEPS-R2 is only 45 percent higher than CAT-R2.[20] In other words, the overlapping policies reduce the cost disparity between DEPS and CAT by nearly 2/3.

The overlapping policies lower costs per ton of abatement under the DEPS while raising costs per ton under CAT. In Phase 3, in the absence of overlaps (the "NO" cases"), costs per ton are 37% lower under CAT; in the presence of overlaps, the cost-differential is reduced to 26%.

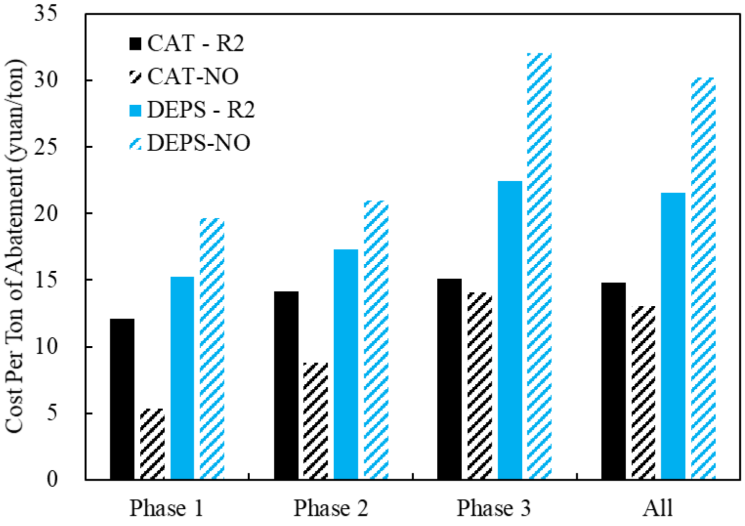

Figure 1. Cost Per Ton of Abatement in Different Phases of CAT and DEPS with and without Overlapping Policies

The detailed simulation results reported in Table 4 reveal three ways that the stated overlapping policies in R2 improve the DEPS's cost-effectiveness. First, the renewable subsidy helps correct the inefficiency from the DEPS's under-allocation of allowances to renewables. The resulting renewables shares—in the "Share of Wind and Solar Electricity Output" panel in

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[20] Table C2 in the appendix presents the complete results for all cases listed in Table 3, illustrating how each component of the overlapping policies helps reduce the cost disparity between DEPS and CAT. The RPS plays the most significant role in increasing the cost of CAT.

Table 4—align better with their levels in the CAT-NO case, which would yield optimal shares in the absence of other market distortions.

Second, the implicit electricity taxes, introduced by the RPS across all consumption and by the IEP for covered industrial sectors, help address the incomplete pass-through of embodied emissions costs under DEPS. As discussed in the theoretical section, both of these policies help to exploit the abatement potential of reduced electricity consumption under a TPS. Results in the "Change in Total Electricity Output" panel of Table 4 show that, during Phases 2 and 3 with the IEP in effect, the decrease in total electricity output under DEPS-R2 surpasses that of DEPS-NO, moving towards the more efficient levels of conservation in CAT-NO. Even so, results in the "Change in (Wholesale) Electricity Prices" panel reveal that electricity prices rise 2.3% under DEPS-R2, less than a quarter of those under CAT-NO. This suggests that consumers are better insulated from cost increases under DEPS-R2.

Third, both the RPS and the IEP lower the carbon price of the DEPS, as the theory section suggested. Since both policies also enhance emissions reductions, the benchmarks are relaxed to meet the same emissions target as without overlaps, amplifying this price reduction. Table 4's "Allowance price" panel shows that the average carbon price of DEPS-R2 in all phases is around 40 percent lower than in DEPS-NO. The value of associated implicit output subsidies under DEPS equals the product of benchmark and carbon prices. The fall in carbon prices exceeds the increase in benchmarks, meaning the distortions from the implicit output subsidy and the benchmark differentiation are also lowered.

It is worth noting that the carbon price that results in these cases does not represent the marginal cost of abatement, but rather the marginal cost of residual abatement. As such, it is not a good indicator of the impact of overlapping policies on marginal abatement costs. In the case of DEPS-R2, both the allowance price and average abatement cost fall relative to DEPS-NO, indicating that overlap improves cost-effectiveness. In contrast, for CAT, any overlapping policy undermines the cost-effectiveness of emissions reduction. In Phases 1 and 2, the cost per ton of abatement of CAT-R2 is 120 percent and 60 percent higher than that of CAT-NO, although allowance prices are lower. The presence of the RPS targets results in an inefficiently high renewable share, particularly in Phases 1 and 2.

Table 4. Results without and with Stated Overlaps

ETS policy:	CAT		DEPS	
Overlap Scenario:	-NO	-R2	-NO	-R2
Cost Per Ton of Abatement (yuan/t)				
Phase 1	5.4	12.1	19.6	15.3
Phase 2	8.8	14.2	21.0	17.3
Phase 3	14.1	15.1	32.0	22.5
All	13.1	14.8	30.2	21.5
Allowance Price (yuan/t)				
Phase 1	27.2	14.5	151.7	64.9
Phase 2	44.2	27.2	143.6	70.9
Phase 3	88.9	79.8	313.3	206.7
All	73.3	62.2	262.3	164.4
Change in (Wholesale) Electricity Price (%)				
Phase 1	4.1	2.3	0.9	0.4
Phase 2	6.5	4.2	1.5	0.8
Phase 3	12.7	11.2	4.1	3.1
All	10.1	8.4	3.1	2.3
Implied Rate of Renewable Subsidy under the RPS (%)				
Phase 1		9.6		11.2
Phase 2		12.5		16.3
Phase 3		2.9		10.3
All		5.7		11.5
Change in Total Electricity Output (%)				
Phase 1	-2.4	-1.3	-1.2	-0.5
Phase 2	-3.8	-3.2	-1.3	-1.4
Phase 3	-7.3	-7.9	-2.8	-4.5
All	-5.9	-6.0	-2.3	-3.3
Share of Wind and Solar Electricity Output (%)				
Phase 1	9.5	11.3	9.0	11.3
Phase 2	14.3	16.8	13.3	16.8
Phase 3	27.8	28.3	25.3	28.3
All	22.3	23.4	20.5	23.4
Leakage Rates (%)				
Phase 1	0.9	0.6	0.2	0.3
Phase 2	1.1	0.9	0.2	0.3
Phase 3	1.2	1.3	0.4	0.3
All	1.2	1.2	0.4	0.3

Note: All the changes refer to percentage changes as compared with the reference scenarios, where there is no ETS or overlapping policy. Leakage rates are emissions leakage to foreign countries as a percentage of domestic emissions reduction.

Finally, we report "Leakage Rates" at the bottom of Table 4. The potential relocation of production and emissions to foreign countries that are not bound or less bound by emissions regulations is an important policy concern for countries implementing carbon pricing in traded sectors. The leakage rate is defined as the rise in emissions abroad relative to the domestic reductions achieved by the climate policy. Its magnitude is assessed using China's import and export data and the average emissions intensity of imported and exported goods. We find that emissions leakage, across all cases, is generally small when compared to China's emissions reduction.[21] Prior literature has demonstrated that TPS can mitigate emissions leakage due to their implicit output subsidies (Fischer & Fox, 2007; Holland, 2012). Our results confirm this: leakage rates under DEPS are approximately a quarter of those observed under the CAT system.

2. Relative contributions of overlapping policies

While Table 4 focused on the stated overlaps, Figure 2 explores the contributions of different policy components to cost reductions under the DEPS, by comparing the impacts of the scenarios S2 and RN, as well as R2. In all three cases, the benchmarks are set to meet the same renewable energy and national emission targets.[22] Here, we focus on Phase 3, when IEP applies to a significant portion (25%) of electricity consumption.

Individually, both IEP and the implicit electricity tax under the RPS improve the cost-effectiveness of the DEPS, with the most benefits coming from the RPS-introduced endogenous electricity taxes. The difference in cost per ton of abatement between the R2 and RN cases under the DEPS highlights the impacts of IEP, which helps reduce the cost by 8%. The difference between the RN and SN cases highlights the impact of RPS-introduced endogenous electricity taxes, which reduce the cost by 17%. The difference between the SN and NO cases reveals the effect of the renewable subsidy, which here is higher than in the RN case in order to meet the same renewable share target; it reduces the cost by 10%.

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[21] We also compared scenarios holding global emissions constant. Since the leakage rates are relatively small, controlling for emissions leakage has little influence on the results and does not affect policy rankings. For this reason, we focus on the cost per ton of domestic emissions reduction in discussions in the following sections.

[22] Table C1 in the appendix presents the full results in all periods.

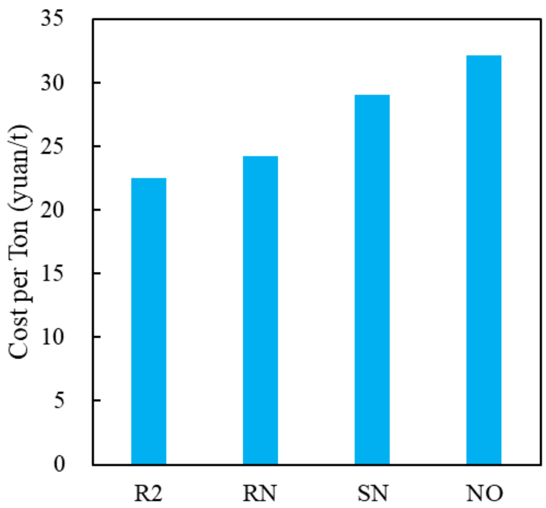

Figure 2. Cost Per Ton of Abatement of DEPS with Alternative Overlapping Policies in Phase 3

Note: See Table 3 for the detailed definitions of different cases. RN removes the indirect emissions price from the preceding scenario, R2. SN removes the implicit electricity tax of the RPS from the preceding scenario. We focus on Phase 3, when a meaningful share of electricity consumption (25%) is subjected to the indirect emissions price.

3. Optimizing overlapping renewable support policies

Up to now, we have focused on overlaps based on actual policy targets. In general, the overlapping subsidies are not at levels that maximize the cost-effectiveness of the TPS-overlap combination. We now consider the extent to which setting one of the overlapping policies—the RPS—at optimal levels can improve cost-effectiveness.

Alternative RPS targets can improve cost-effectiveness in two main ways: 1) by better adjusting renewable electricity incentives relative to competitors under an EPS, and 2) by improving price signals for consumers of electricity. Figure 3 below displays results from a set of simulations[23] that reveals the relationship between the cost per ton of abatement and non-hydro renewable share targets set by the RPS, for both the DEPS (blue line) and CAT (black line). The figure also shows the implicit renewable subsidy rates associated with each RPS target (marked with red circles) and identifies the overlapping policies that minimize average abatement costs (blue triangles).

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[23] We adopted a grid simulation approach, with a subsidy rate of 0.5% as steps to simulate the relationship between the rate of renewable subsidy and cost per ton. In each simulation, these renewable subsidies are assumed to remain constant from 2020 to 2035. Therefore, the "optimal subsidy" or "optimal RPS targets" discussed in this paper refer to renewable subsidy rates or share targets that can achieve the minimum average cost per ton and remain constant in the corresponding phase.

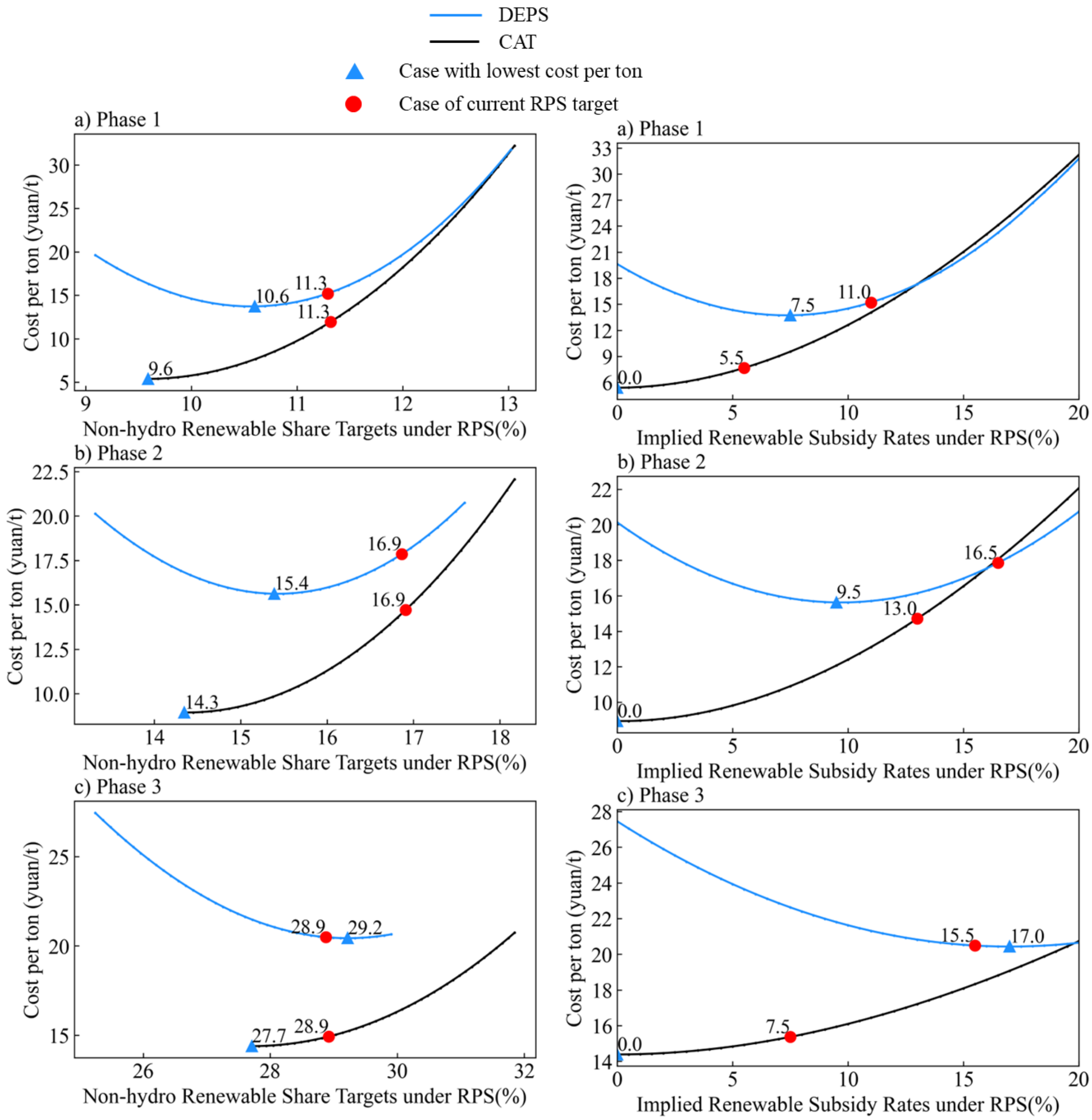

Figure 3. Relationship between Cost Per Ton Abatement, Non-Hydro Renewable Share Targets, and the Corresponding Implied Renewable Subsidy Rates in Different Cases.

Note: The left panel shows the relationship between cost per ton and non-hydro renewable share targets under the RPS, and the right panel shows *the same* cases, in which the lines indicate the corresponding implied renewable subsidy rates under the RPS. In all cases, IEP is also implemented. Numbers indicate the corresponding wind and solar shares target under the RPS or the implied renewable subsidy rates under the RPS.

Figure 3 reveals that the stated-policy RPS share and associated renewable subsidy (the red dot on the blue line) is higher than what would best complement the DEPS (the blue triangle on the blue line) in the first two phases, but a bit lower than optimal in the third phase. It shows that cost-effectiveness under CAT is maximized with a non-binding RPS and no overlapping subsidy.

It is interesting to note from the right-hand panels that the lines for CAT and DEPS cross, revealing that, beyond a sufficiently high renewable (and tax-funded) subsidy, the cost-effectiveness advantage of CAT relative to the DEPS disappears. Under such circumstances, CAT exacerbates the over-supply of renewables, while the benchmark differentiation of the DEPS that excludes renewables helps counteract it.

By contrast, the lines do not cross for any given RPS target within the range of the left-hand panels. This reveals a benefit of having a renewables support instrument with its own tradable credit mechanism, which allows the subsidies to adjust to the choice of ETS. Since CAT provides more incentives for renewables through its carbon price pass-through, a smaller, less-distorting renewables subsidy is needed; with the DEPS, a higher subsidy is needed to offset the lack of benchmark allocation to renewables and the less efficient incentives. The fact that suboptimal overlapping policies can change the rankings of ETS policies underscores the importance of evaluating them together. Overall, we find that optimizing the RPS that accompanies China's DEPS can lower costs per ton by about 10% compared to the actual RPS.[24]

4. Optimized overlapping policies under different ETSs

The above sections focus on cases where policies overlap with China's DEPS. Here we discuss cases involving overlaps with different forms of the ETS. Such cases are policy-relevant, since China continues to consider alternative ETS designs.

Table 5 shows the optimized renewable subsidy rates in the different cases. As mentioned, under CAT no subsidy is warranted, whether or not embodied emissions are priced and whether the subsidy is independent or electricity tax-funded. Nor can an independent renewable subsidy lower costs under a USPS. However, a USPS can benefit from a modest RPS,

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[24] Theoretically, one could further enhance the cost-effectiveness of TPSs through an exogenously optimized electricity tax rate. However, our findings indicate that when a significant portion of electricity consumers are covered by the IEP in Phase 3, the system can already capture most of the cost-saving opportunities from policy overlap. In Appendix C, we explore the cost-saving potential of an optimized electricity tax. Such a tax can further reduce costs by roughly another 10% compared to optimized RPS with DEPS. Both of these improvements, while not negligible, are relatively modest compared to the nearly 40% cost savings of optimized RPS with DEPS over DEPS-NO.

due to the implicit electricity tax component introduced by the RPS. Both the UEPS and DEPS benefit directly from the independent renewable subsidies, as proper levels of renewable subsidy can address the output subsidy disparities and level the playing field between renewable and fossil-based plants in both systems; implementation with RPS can confer additional benefits.

Optimized subsidy rates vary based on the type of TPS and other overlapping policies. With IEP in place, the allowance price decreases, reducing implicit output subsidies for fossil-based plants and necessitating smaller renewable subsidies to compensate for the distortions. When the renewable support policy is an RPS rather than an independent subsidy, the optimized subsidy level is significantly higher, as higher renewable subsidies under RPS not only provide support for renewables but also raise the implicit electricity tax, enhancing cost-effectiveness. The IEP then allows an even greater reduction in the renewable subsidy, since the improved carbon cost pass-through to consumers means less implicit tax is needed from the RPS.

Table 5. Optimized Renewable Subsidy Rates under Different ETSs (%)

	Type of ETS			
Overlapping Policies	**CAT**	**USPS**	**UEPS**	**DEPS**
RPS+IEP (R*2)	0.0	2.0	12.0	14.0
RPS (R*N)	0.0	2.5	13.5	16.0
IRS+IEP (S*2)	0.0	0.0	7.5	9.0
IRS (S*N)	0.0	0.0	8.0	10.0

Note: See Table 3 for the definitions of the overlapping policies. The asterisk (*) represents the cases with optimal renewable subsidy rates. Optimal renewable subsidy rates shown here refer to the renewable subsidy level that leads to the lowest cost per ton over the entire simulation period.

Figure 4 compares the outcomes of cost-minimizing overlapping policies across ETS types and phases.[25] The least-cost policy enabling China to achieve its emission targets is CAT with no overlapping policies.[26] Evidently, if the ETS is a CAT, additional policies are not needed for emissions reductions. Nevertheless, if the ETS is a TPS, abatement costs can be reduced by optimizing the overlapping RPS. For all of the TPS options in Table 3, the best-performing overlapping policy combines an optimized RPS together with the IEP. Each of these policies

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[25] A full set of results of all policy cases are provided in Table C2 in Appendix C.

[26] Although the numerical model includes several features (more sectors, international trade, and general equilibrium effects) not incorporated in the theroretial model, these numerical findings reinforce the theoretical model’s predictions.

would benefit from electricity taxes, whether the taxes are implemented through IEP, implicitly through RPS, or both, as they address the incomplete carbon price pass-through.

Figure 4 also provides information on the implications of ETS reform. China would clearly benefit from a transition from its current DEPS to a UEPS, regardless of the presence of overlapping policies. The DEPS's differentiated benchmarks introduce efficiency costs, and the overlapping policies considered here cannot eliminate these inefficiencies. While the efficiency sacrifices under the DEPS are significant, the cost-effectiveness differences between the UEPS and USPS are negligible, as the overlapping RPS targets can almost fully address the inefficiencies caused by the exclusion of renewables under the UEPS. Finally, for all types of TPSs, even with the optimal overlapping policies considered in this study, their cost-effectiveness remains lower than that of a CAT system without overlaps.

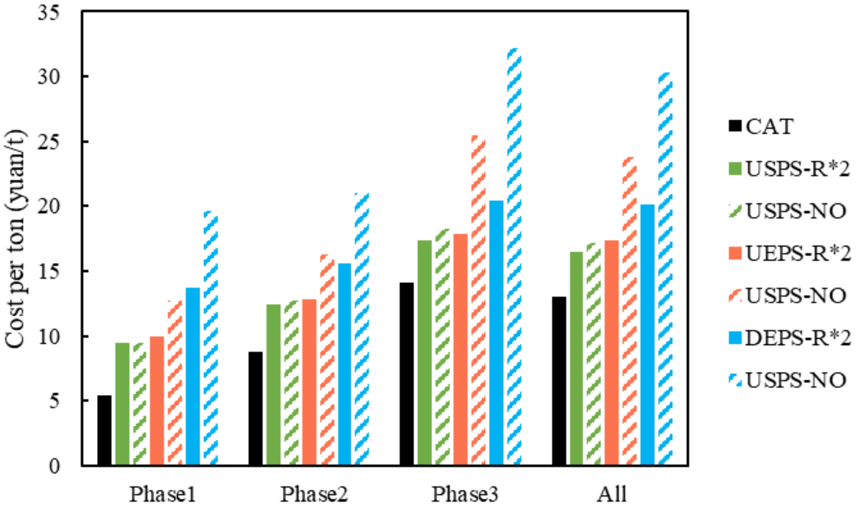

Figure 4. Cost Per Ton of Abatement in Different Phases of with and without Optimal Overlapping Policies

Note: For CAT, the optimal overlapping policies are no overlaps. "Optimal" overlapping policies of different TPS refer to the overlapping policies that yield the lowest cost per ton in each case to meet the same emissions target, among all considered overlapping policy cases in section III C. See appendix for the full result.

IV. Sensitivity Analysis

We have examined the sensitivity of results to a range of key parameters of the numerical model. Detailed results are provided and discussed in the appendix. We find that as it becomes easier to reduce energy intensity through factor-energy input substitution, the cost-effectiveness gap between the DEPS-NO and CAT-NO cases narrows, and the necessity for overlapping policies such as RPS and IEP diminishes. This follows from the fact that when it is easier to reduce the emission intensity within a given subsector, the need for fuel switching and energy efficiency improvements also decreases, lowering the need for overlapping policies to compensate for DEPS's inefficient use of these channels.

We also find that lowering capital transformation elasticities between subsectors of a given sector and raising the electricity demand elasticity both produce ambiguous impacts on the cost-effectiveness gap between DEPS-NO and CAT-NO, as it may increase or decrease the distortions brought by the implicit output subsidies under the DEPS. Regarding the effectiveness of overlapping policies, we find that altering capital transformation elasticity has a minimal impact, while a higher electricity demand elasticity enhances the benefits of implementing an electricity consumption tax, either through RPS or IEP.

Although quantitative outcomes depend on the parameters employed, our sensitivity analysis indicates that our main qualitative findings are robust over a wide range of parameter choices. Overlapping policies have quantitatively important implications for the cost of meeting emissions targets, as well as for other variables of concern, including prices and output levels. Furthermore, the choice of ETS matters a great deal for the consequences of overlapping policies and the resulting cost-effectiveness of the policy portfolio.

V. Conclusion

As part of meeting their nationally determined commitments under the Paris Agreement, nearly all countries have clean energy plans and CO_2 emission reduction goals. In most cases, countries aiming to achieve given clean energy and emissions targets will employ multiple policies to achieve the goals. Interactions across the policies significantly affect the outcomes.

Policy mixes often include both an emissions trading system and other policy instruments, such as subsidies to low-emitting fuels or taxes on electricity use. In the past, the ETSs have tended to take the form of cap and trade, but an increasing number of newer entrants to emissions trading employ rate-based approaches, where total emissions become a function of total output and the performance benchmarks set by the regulation.

Given the prevalence of overlapping policies, it is important to understand the nature of their interactions and the associated economic consequences. Such considerations should inform the choices both of emissions trading systems and of subsidies and other policies to promote transitions to low-carbon energy supplies.

Our analytical model reveals how outcomes differ depending on the nature of the ETS and the types of policies with which it overlaps. It highlights when overlapping policies may have counterproductive impacts with rate-based ETSs, and when they can enhance effectiveness in ways that differ from the effects with mass-based trading systems. The insights are complemented by results from a numerical general equilibrium model representing important characteristics of the recently implemented Chinese nationwide ETS context.

Several features of rate-based systems compromise efficiency, but the judicious use of overlapping policies can offset a substantial share of the potential efficiency losses. One source of inefficiency stems from the implicit subsidies to output inherent in rate-based allowance allocation. We show that this output-related distortion can be offset by combining a renewables subsidy with an electricity consumption tax (as in the case of renewable portfolio standards or feed-in tariffs with surcharge), or by putting a price on the embodied emissions in all or part of the electricity consumption. A second source of inefficiency relates to the relative support for different sources of energy. The cost-effectiveness of emitter performance standards is handicapped as a result of its exclusion of clean sources from the carbon market. Support for renewable production can offset this limitation and thus boost cost-effectiveness.

In our simulations for China's context, pricing embodied emissions of industrial consumers—even if they only represent 25% of electricity consumption in the third phase—can lower the cost per ton by up to 8%. An optimized independent renewable subsidy can reduce the overall average cost per ton by 9%-15%, depending on the phase. By addressing both sources of inefficiency, using an RPS to meet China's existing renewable energy target can reduce the cost per ton of abatement by 24% over all three phases of the given ETS. If those renewable share targets were better aligned with China's TPS, the existing system's cost-effectiveness could be further enhanced by approximately 10% in all three phases.

Overlapping policies also influence the cost-effectiveness of cap and trade. Without overlapping policies (and absent other market failures), CAT is the most cost-effective ETS option, since it avoids introducing output subsidies that distort incentives to switch between energy sources as a means to reduce emissions. CAT also encourages efficient pass-through of emissions costs, meaning additional taxation of electricity is not needed. Thus, overlapping the stated RPS and embodied emissions pricing increases by about 10% the costs of a CAT system that would achieve the same emissions reductions as China's actual TPS. Together, China's stated policy overlaps reduce the cost differential between China's TPS and an equivalently stringent CAT system by about two thirds.

These insights are relevant not only to China, but also to other countries considering or implementing a rate-based ETS, such as Indonesia, Kazakhstan, and India, as well as Canada.

In future work, we plan to consider how other pre-existing distortions or market failures might influence the outcomes from overlaps and suggest useful policy responses. For example, output-based allocations can have some benefits in the presence of distortionary taxes on labor, capital, or other factors of production, or investment dynamics under macroeconomic volatility. Clean energy policies are often needed to address technology market failures. Another area for extension is attention to the effects of a range of flexibility mechanisms often incorporated into ETSs to address uncertainty, including banking and borrowing, price corridors, or quantity adjustment mechanisms that make mass-based emissions targets more malleable. Incorporating more real-world policy settings and constraints would provide needed nuance to the recommendations for optimal ETS design and supplemental policy recommendations.

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