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Policy Innovation in Volatile Organic Compound Control: International Experience and Implementation Readiness of China's VOC Environmental Protection Tax Pilot

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Abstract: As an emerging market-based instrument for air pollution control, China will begin levying an environmental protection tax on volatile organic compounds (VOCs) on a pilot basis on 1 January 2027 under the Pilot Measures for Levying Environmental Protection Tax on Volatile Organic Compounds. The institutional framework has been settled, but supporting rules such as source-category calculation methods and provincial applicable tax amounts are still pending. To support implementation, this study reviewed the operating rules of VOC-related taxes, charges and economic incentives in the South Coast Air Quality Management District of the United States, Switzerland, Japan and the Taiwan region of China, and compared them item by item with China's pilot scheme along four dimensions: the location of the price signal and tax base, scope and thresholds, quantification and verification, and rates and incentives. The reviewed cases represent three approaches—emission-stage charging, supply-side taxation and investment-side incentives—and their performance depends mainly on the rules for identifying the tax base, quantifying emissions, verifying filings and designing incentives. China's pilot shares comparable mechanisms with these systems in emission-stage taxation, source-specific quantification and deemed assessment for misreporting. At the same time, it introduces institutional innovations that connect the new tax with existing environmental tax, pollutant discharge permitting and performance grading systems: the deduction of 18 separately taxed VOC species after source-category aggregation, the separate taxation of VOCs as a whole, and tax relief linked to environmental performance grades. Implementation preparations should give priority to issuing source-category calculation methods and verification feedback rules, and use pilot data to evaluate simplified administration for small emitters, provincial tax amounts, permit-based taxpayer identification and the tax application of performance grades.

Keywords: Volatile Organic Compounds, Environmental Protection Tax, Economic Instruments, Policy Innovation, International Comparison.

1. Introduction

Volatile organic compounds (VOCs) are important precursors of ozone (O_3) and secondary fine particulate matter ($PM_{2.5}$) [1]. While $PM_{2.5}$ concentrations in China have declined steadily in recent years, ozone pollution control remains a pressing challenge, and VOC emission reduction has become a key element of coordinated air pollution control. VOC emissions arise from numerous source categories with a high share of fugitive emissions, spanning the use of raw and auxiliary materials, storage and loading, equipment leaks and wastewater volatilisation, which makes emission quantification and supervision complex [2]. Alongside tighter emission standards and process controls, economic instruments such as taxes and charges can complement administrative regulation through price signals and create continuous incentives for emission reduction. Experience with China's national carbon emissions trading market, launched in July 2021, likewise shows that policy settings such as allowance supply directly shape the price signal faced by enterprises [3], which is consistent with the broader view that the performance of market-based instruments depends on their design and on monitoring and enforcement conditions [4].

China's price-based regulation of overall VOC emissions began in 2015, when the Ministry of Finance, the National Development and Reform Commission and the former Ministry of Environmental Protection issued the Pilot Measures for Levying Pollutant Discharge Fees on Volatile Organic Compounds (Cai Shui [2015] No. 71), which launched VOC discharge fee pilots first in the petrochemical and packaging and printing industries [5]. The Environmental Protection Tax Law of the People's Republic of China was enacted in 2016. Owing to the limited monitoring and quantification capacity at that time, only 18 VOC species with toxic or odorous properties, such as benzene, toluene and formaldehyde, were listed as taxable air pollutants, and other VOCs were not taxed [6]. In October 2025, the Standing Committee of the National People's Congress amended the Environmental Protection Tax Law and authorised the State Council to pilot an environmental protection tax on VOCs [7]. In July 2026, the Ministry of Finance, the State Taxation Administration and the Ministry of Ecology and Environment (MEE) jointly issued the Pilot Measures for Levying Environmental Protection Tax on Volatile Organic Compounds (Cai Shui [2026] No. 50, hereinafter "the Pilot Measures"). From 1 January 2027, the pilot covers eight industries: printing; petroleum, coal and other fuel processing; chemical raw materials and chemical products manufacturing;

pharmaceutical manufacturing; iron and steel making; general equipment manufacturing; special equipment manufacturing; and automobile manufacturing. The Pilot Measures establish the basic rules on taxpayers, the range of tax amounts, emission source categories and quantification methods, while the specific calculation methods for each source category are to be issued separately by the MEE together with the Ministry of Finance and the State Taxation Administration [8].

The pilot is a notable institutional innovation in China's environmental policy. Rather than creating a stand-alone levy, it extends the existing environmental protection tax to VOCs as a whole, identifies taxpayers through the pollutant discharge permit system, and links tax relief to environmental performance grading. How such an emission-based tax can be made calculable, verifiable and administrable is also of interest beyond China, because the jurisdictions that have priced VOCs have done so at different points of the material and emission chain and with different supporting rules.

Existing studies have discussed VOC-related environmental taxes and charges in terms of tax scope, tax design, environmental and economic effects and emission quantification. Chen and Dai [9] analysed the boundaries, tax burden and administrative basis for including VOCs in the environmental protection tax. Pan et al. [10] and Qian et al. [11] evaluated the emission reduction and economic impacts of different taxation scenarios in Hebei Province and at the national scale, respectively. Chen et al. [12] compared VOC quantification methods and their applicable conditions in key industries, and Yang [13] discussed the design of taxable items, rates and tax incentives in China with reference to the Swiss VOC incentive tax. Most of these studies were completed before the Pilot Measures were issued; specific provisions such as source-category aggregation with deduction, deemed assessment and performance-based tax relief have therefore received little attention, and the operating rules of foreign systems have rarely been compared item by item with the provisions of China's pilot.

The choice of environmental policy instruments needs to consider cost-effectiveness, the costs of emission monitoring and enforcement, and institutional feasibility [4]. The VOC economic instruments of the South Coast Air Quality Management District (SCAQMD) in the United States, Switzerland, Japan and the Taiwan region of China have operated for relatively long periods, are supported by comparatively complete regulatory and statistical documentation, and act on different stages, namely emissions, substance supply and abatement investment. Taking these four jurisdictions as comparators, this paper compares their rules with the Pilot Measures along four dimensions—the location of the economic signal and tax base, scope and thresholds, quantification and verification, and rates and incentives—with the aim of informing the formulation of supporting rules and provincial implementation preparations, and of providing a policy-design reference for other jurisdictions considering price-based VOC control.

2. International Practice of VOC-Related Economic Instruments

2.1. United States: permit fees and local emission fees

The United States has no nationwide VOC emission fee collected directly by the federal Environmental Protection Agency (EPA). Under the Clean Air Act, emission standards and technical rules are established at the federal level, while state and local air quality agencies levy fees on air pollutants, including VOCs, according to local air quality conditions and regulatory costs [14]. Title V of the Clean Air Act requires major stationary sources to obtain operating permits, with permit thresholds varying by pollutant and by the severity of ozone nonattainment [15]. Permit fees are mainly intended to cover the reasonable costs of running the permit programme, and fee levels are set by each permitting authority [16]. Although such fees are not designed primarily to regulate emissions, facilities with larger emissions pay more, which creates a certain incentive to reduce emissions.

The SCAQMD is a representative example of emission-based charging. Its Rule 301 places permit-related fees and annual emission fees in a single rule. Permitted facilities first pay annual permit fees; in addition, facilities whose annual emissions reach 4 t of VOCs, NO_x, SO_x or particulate matter, or 100 t of CO, must report the previous calendar year's emissions through the Annual Emissions Reporting (AER) system and pay emission fees at pollutant-specific rates. Annual emissions are calculated from fuel and material usage, production, emission factors and control efficiencies [17], and the district provides dedicated calculation guidance and default emission factors for source types such as coating operations, storage tanks and combustion equipment [18].

Another type of fee is triggered by ozone attainment status. Section 185 of the Clean Air Act provides that, where a severe or extreme ozone nonattainment area fails to attain the standard by the statutory deadline, major stationary sources of VOCs in the area must pay an annual nonattainment fee on emissions exceeding 80% of their baseline emissions; the same requirement applies to major stationary sources of NO_x [14, 19]. The SCAQMD adopted Rule 317.1 on this basis [20].

2.2. Switzerland: the VOC incentive tax and the commitment procedure

Switzerland is one of the few countries with a nationwide environmental tax dedicated to VOCs. The tax is levied under Articles 35a and 35c of the Environmental Protection Act and the Ordinance on the Incentive Tax on Volatile Organic Compounds (OVOC, SR 814.018) and has been collected since 1 January 2000. The rate was CHF 2 per kg at introduction, was raised to CHF 3 per kg in 2003, and has not been adjusted since [21, 22]. The Federal Office for Customs and Border Security is responsible for collection and refunds, while the Federal Office for the Environment participates in implementation and effectiveness evaluation [22, 23].

The tax is levied not on VOCs emitted to the atmosphere by enterprises, but on VOC substances and VOC-containing products imported into or produced in Switzerland. Importers and domestic producers are the taxpayers, and the tax is calculated on the mass of taxable VOCs [21]. The taxable scope is defined by positive lists in the annexes: listed VOC substances are taxable, and listed products are taxable when their VOC mass fraction exceeds 3%. VOCs used as fuel, exported, or used and treated in ways that prevent their release to the environment may be exempted or refunded in accordance with the regulations [22]. Because the tax is collected centrally at the import and production stages, administration focuses on a limited number of importers and producers and does not require emission quantification at

each downstream emission point.

To avoid taxing VOCs that are not actually released, the OVOC provides a commitment procedure. Authorised purchasers that reach a specified turnover may purchase VOCs temporarily free of tax, but must prepare an annual VOC balance that records stocks, purchases, quantities leaving with products, recovery and disposal, tax-exempt uses and releases to the environment; the authority then settles the tax on this basis [22]. Upstream taxation is thereby reconnected with actual downstream releases. VOCs used in installations whose emission controls are substantially stricter than legal requirements may be exempted under specified conditions, and tax revenue is returned to residents through health insurers [22, 23].

2.3. Japan: regulation, voluntary reduction and investment support

Japan has not established a dedicated environmental tax or discharge fee levied continuously on enterprises' VOC emissions. Following the 2004 amendment of the Air Pollution Control Act, Japan adopted a VOC control framework combining legal regulation with voluntary action by industry. From April 2006, six categories of designated facilities—chemical manufacturing, coating, adhesion, printing, industrial cleaning and VOC storage—became subject to notification requirements and emission standards [24]. Beyond statutory controls, the Ministry of Economy, Trade and Industry organised industry associations and enterprises to undertake voluntary reductions and evaluated sectoral progress annually [25].

To support emission controls, Japan introduced dedicated tax and financing support for VOC abatement investment. Under measures announced by the Ministry of the Environment in 2005, qualifying VOC emission control equipment was eligible for first-year special depreciation of 14% for income tax and corporate tax purposes, preferential tax bases for fixed asset tax and business office tax, and policy-based financing [26]. After the fiscal year 2010 tax reform, VOC emission control equipment was no longer eligible for the special depreciation for pollution prevention equipment [27], whereas policy-based financing was retained: the current Environment and Energy Countermeasure Fund of the Japan Finance Corporation still covers VOC emission control [28]. Unlike emission-based charging in the United States and substance-based taxation in Switzerland, Japan's economic incentives arise only when enterprises purchase abatement equipment or apply for financing, serving as an investment-side complement to legal regulation and voluntary reduction.

Japan set a target of reducing VOC emissions from stationary sources by about 30% in fiscal year 2010 relative to fiscal year 2000. The revised emission inventory published by the Ministry of the Environment shows that VOC emissions in fiscal year 2010 were about 791,000 t, 44.1% lower than in fiscal year 2000, exceeding the original target [29].

2.4. Taiwan region of China: air pollution control fees on stationary sources

The Taiwan region of China levies air pollution control fees on stationary pollution sources under its Air Pollution Control Act and the Regulations Governing the Collection of Air Pollution Control Fees, and VOCs have been included since 2007 [30, 31]. Since 2010, additional fees have been levied on 13 hazardous individual VOC species, and three more species—vinyl chloride, 1,3-butadiene and acrylonitrile—were added in 2023 [32]. Owners, actual users or managers of stationary sources file returns and pay fees quarterly; the regional environmental authority is responsible for the fee system and rates, while local authorities participate in verification and in reviewing fee reductions [31].

The VOC fee is calculated as emissions multiplied by the applicable rate. Rates are tiered by quarterly emission scale and differentiated by air pollution control zone and season, with higher rates in the first and fourth quarters, when air quality is poorer [33]. Sources emitting 1 t of VOCs or less per quarter are not required to pay VOC or individual-species fees [33], and sources whose reported quarterly emissions of sulphur oxides, nitrogen oxides, VOCs and particulate matter do not exceed 10 kg are exempted from filing for that pollutant [31]. The separate payment threshold and filing exemption create tiered management of both the fee burden and the reporting burden of small sources.

Emissions may be calculated using approved plant-specific VOC factors, test results, emission factors and control efficiencies published by the authority, or mass balance, and enterprises must keep records of raw and auxiliary materials, production, operation of control equipment, waste solvents and recovered quantities for verification. Verification results are linked to subsequent quantification methods: where a site using the emission factor method reports quarterly emissions that differ from the authority's verified result by a factor of two or more and by at least 7.5 t, it must switch to the mass balance method from the quarter following receipt of the notice [31]. Once a deviation is confirmed, the enterprise must calculate emissions on the basis of material data in all subsequent quarters, which limits the scope for under-reporting through continued use of the factor method.

In addition, fee reductions may be granted for qualifying VOC control equipment. For newly installed destructive equipment, the reduction is set at 30% of the purchase cost, up to NT$5 million per unit; for non-destructive equipment, it is 20%, up to NT$2 million per unit; existing equipment qualifies for lower rates and ceilings; and the total annual reduction is capped with reference to the VOC fees actually paid in the year before application [34]. Emission-based charging and support for abatement investment thus operate in parallel within the same system.

3. Comparative Analysis of the Foreign Systems

The main institutional features of the four jurisdictions and China's pilot are summarised in Table 1.

Table 1. Comparison of the main institutional mechanisms of VOC economic instruments.

Jurisdiction / instrument	Stage of action and institutional basis	Scope and thresholds	Basis of charge or support	Quantification, reporting and incentive constraints
United States (SCAQMD)	Local charges based on emissions under the federal Clean Air Act permit framework	Facilities emitting ≥4 t per year of VOCs or other listed pollutants must file AER and pay emission fees; separate thresholds for Title V major sources	Permit fees + fees based on emissions; separate nonattainment fees under Section 185	Calculated from fuel, materials, production, emission factors and control efficiencies; annual emission reporting
Switzerland: VOC incentive tax	Tax levied only at the import and domestic production stages	Positive lists define taxable substances and products; products with VOC mass fraction ≤3% exempt; turnover condition for the commitment procedure	Mass of taxable VOCs × CHF 3/kg	Annual VOC balance under the commitment procedure; tax settled on actual releases; revenue returned to residents via health insurers
Japan: support for abatement investment	Statutory emission control + voluntary industry reduction; economic support acts on abatement investment	Six categories of designated VOC facilities; support determined by equipment or financing eligibility	Former special depreciation and other tax incentives for abatement equipment (no longer applicable after FY2009); policy financing	No continuous charge on residual VOC emissions
Taiwan region of China: air pollution control fee on stationary sources	Charge at the emission stage on stationary sources	No VOC fee at ≤1 t per quarter; filing exemption at ≤10 kg per quarter	Emissions × tiered rate; rates differentiated by area and season; additional fees on hazardous individual species	Multiple quantification routes; switch to mass balance from the next quarter once the deviation under the factor method reaches the threshold; fee reductions for control equipment
China: VOC environmental protection tax pilot	First batch of industries; taxpayers identified via discharge permits; taxation at the emission stage	Eight pilot industries; not levied for the time being where permits do not designate VOCs; technical boundaries by source category	Taxable emissions of eight source categories ÷ 0.95 kg × provincial tax amount (CNY 8 to 12 per pollution equivalent), less 18 individually taxed species	Prescribed quantification method per source category; mainly quarterly filing; deemed assessment for misreporting; Grade A and Grade B taxpayers pay 50% and 75%

3.1. Stage of the economic signal and basis of charging

According to the stage at which the economic signal acts, the four jurisdictions can be grouped into three approaches: the SCAQMD and the Taiwan region of China charge at the emission stage, Switzerland taxes at the supply stage, and Japan provides incentives at the stage of abatement investment. The three types of instruments address different management problems. Emission-stage charging is most directly linked to emission behaviour, but it relies on enterprises continuously providing data on activity levels, VOC content and control efficiencies, and therefore places high demands on emission quantification and verification capacity [17, 33]. Switzerland moves the tax base upstream, reducing the administrative burden of end-of-pipe source-by-source measurement, and uses annual VOC balances to link the final tax burden of large users to their actual releases [22]. Japan encourages abatement by reducing the costs of equipment investment and financing, but does not continuously price residual emissions [26, 28].

3.2. Threshold design and rate structure

All the systems use thresholds, but their legal functions differ. In the SCAQMD, 4 t/a marks the boundary above which facilities must submit annual emission reports and pay emission-based fees, while permitted facilities below that level still pay permit fees [17]. The Taiwan region of China uses 1 t per quarter as the payment threshold for VOC fees and 10 kg per quarter as the filing exemption [31, 33]. The Swiss turnover condition determines whether a purchaser may enter the commitment procedure rather than whether VOCs are taxable [22], and Japan's investment support is determined by equipment and financing eligibility, with no emission threshold [28]. In terms of rates, Switzerland applies a uniform rate; the Taiwan region of China differentiates fees by emission scale, area and season; US permit fees mainly cover regulatory costs, whereas Section 185 fees are triggered by ozone nonattainment [16, 19, 22, 33]. Thresholds and rates thus serve, respectively, to screen the administered population, control reporting costs and strengthen abatement incentives in critical periods.

3.3. Quantification methods and reporting constraints

For emission-stage charging systems, the ability to calculate emissions in a stable and verifiable manner is a precondition for the operation of the price instrument. The SCAQMD constrains reporting through uniform calculation rules and default emission factors [17, 18]; the Taiwan region of China also allows several quantification methods but sets quantitative verification triggers for the emission factor method [31]. Both embed verification in subsequent administration; the difference is that the latter directly adjusts the subsequent quantification method on the basis of verification results. Experience with carbon pricing points in the same direction: the EU Emissions Trading System operates on harmonised rules for monitoring and reporting emissions [35, 36], and its unified accounting standards provide a continuous and consistent emission data foundation for the market and for policy evaluation [37].

4. China's Pilot Scheme and Implementation Readiness

4.1. Mechanisms comparable with foreign practice

(1) Taxation is levied directly on emission behaviour. The Pilot Measures designate enterprises, public institutions and other producers and operators that directly discharge VOCs other than those specified in the Table of Taxable Pollutants and Pollution Equivalent Values as taxpayers, and identify tax sources on the basis of pollutant discharge permit management and the VOC designation in permits. Where a unit is not subject to permit management, or its permit does not designate VOC emissions, the tax is not levied for the time being. The tax amount ranges from CNY 8 to 12 per pollution equivalent, with the specific applicable amount determined by provincial governments [8]. Taxing at the emission stage is comparable with the emission-based charges in the SCAQMD and the Taiwan region of China. The difference is that China adopts the form of an environmental protection tax and uses the pollution equivalent as the basis for calculating tax payable. Moreover, instead of setting a tax-free threshold based on emission scale, China's pilot sets technical boundaries at the source-category level: VOC-containing raw and auxiliary materials and volatile organic liquids are covered when their VOC mass fraction is at least 10%; the storage source category is limited to tanks with a single-tank volume of 20 m^3 or more; and the equipment and component leak source category applies to dischargers with at least 2,000 sealing points [8].

(2) Quantification methods are assigned by source category. Article 9 of the Pilot Measures stipulates that taxable emissions are calculated separately for the eight source categories listed in the VOC Emission Source Category List and then aggregated, and Article 10 specifies that the material balance method applies to the use of VOC-containing raw and auxiliary materials, the monitoring method or the emission factor method applies to equipment and component leaks, and the emission factor method applies mainly to the other source categories [8]. This is similar to the practice in the United States and the Taiwan region of China of choosing quantification routes according to source characteristics, although jurisdictions differ in the applicable conditions and priority of methods and in post-verification adjustment mechanisms.

(3) All the systems discipline data quality by attaching adverse consequences to misreporting. Article 17 of the Pilot Measures stipulates that where a taxpayer omits source categories, under-reports a single source category by more than 40%, or tampers with or falsifies monitoring data, VOC content test data of raw and auxiliary materials, or leak detection and repair data, emissions from some source categories are re-determined using prescribed methods. Specifically, five source categories, including the use of VOC-containing raw and auxiliary materials, are assessed on the basis of VOC generation in the current period, while equipment and component leaks, open recirculating cooling water and flares are assessed at 1.5 times the result of the emission factor method. Where the 18 individually taxed species are falsely deducted, their emissions during the period of false deduction are deducted at 0.5 times the first valid monitoring data obtained after the violation is established [8]. Compared with the Taiwan region of China, China's rules focus on deeming the tax base for the current period but do not adjust the subsequent quantification method.

4.2. Localised institutional innovations

(1) Source-category aggregation with deduction of 18 individual species. Under the Pilot Measures, emissions from the eight source categories in the VOC Emission Source Category List are calculated separately and aggregated, and the emissions of 18 VOC species already taxed as individual air pollutants in the same period, such as benzene, toluene, xylene and formaldehyde, are then deducted to avoid double taxation between the overall VOC tax and the existing taxes on individual substances [8]. By contrast, the Taiwan region of China levies additional fees on hazardous individual species [32]; the approach of deducting after source-category aggregation was not found in the other jurisdictions examined.

(2) Separate taxation of VOCs as a whole. The Pilot Measures provide that VOCs as a whole are taxed separately as one category of air pollutant, outside the general ranking rule for taxable air pollutants, with a pollution equivalent value of 0.95 kg [8]. Because the pollution equivalent value of VOCs is the same as those of sulphur dioxide and nitrogen oxides, including VOCs in the ranking of pollutants at each outlet could alter the existing ranking of taxable pollutants at that outlet. Separate taxation therefore reconciles the overall VOC tax with the existing ranking rules.

(3) Tax relief linked to environmental performance grading. The Pilot Measures provide that taxpayers rated Grade A or Grade B in the national environmental performance grading of key industries pay 50% and 75% of the VOC tax payable, respectively, and that VOCs are not eligible for concentration-based tax relief [8, 38]. Under the current environmental protection tax, taxable air pollutants discharged at concentrations 30% or 50% below the applicable standards are taxed at 75% or 50%, respectively [39]. However, fugitive emissions account for a large share of VOC emissions, so stack concentrations cannot reflect an enterprise's overall control level. Performance grading assesses equipment, processes, control technologies, fugitive emission control, monitoring and environmental management, thereby linking VOC tax relief to the enterprise's whole-process environmental management.

4.3. Key issues in implementation preparation

First, source-category calculation methods and verification feedback rules remain to be specified. The specific calculation methods are to be issued separately by the MEE together with the Ministry of Finance and the State Taxation Administration, and supporting documents are expected to provide calculation methods for each source category as well as waste gas capture and removal efficiencies [6, 8]. For enterprises, parameter values and data sources determine how source-category ledgers are established; for tax authorities, calculation rules determine the criteria for return review and on-site verification. In addition, although a 30-day time limit applies to inter-agency notification and review, there is no provision on how verification deviations should affect subsequent parameters or quantification methods [8].

Second, the administrative costs of small emitters need to be evaluated. The pilot sets no emission-based tax-free threshold, and emission scales vary widely among enterprises within the same industry. Operational data are not yet available to determine whether the quantification, testing and filing costs of small sources are commensurate with their tax payable.

Third, provincial tax amounts and the scope for differentiation require study. Different tax levels and scopes lead to markedly different emission reduction and economic effects [10, 11]. The Taiwan region of China differentiates rates by season, and Section 185 in the United States links charge intensity to regional attainment status [19, 33], whereas the Pilot Measures do not provide for intra-provincial differentiation by area or season, and the boundary of provincial authority in setting tax amounts remains to be clarified.

Fourth, the completeness of permit information needs to be checked. Relying on pollutant discharge permits to identify taxpayers avoids the need to build a separate tax source identification system at the start of the pilot, but whether permits designate VOC emissions and whether source-category information is consistent with actual production directly determine whether taxpayers can be accurately identified.

Fifth, the tax application of performance grades needs to be harmonised. Provincial ecology and environment departments may set stricter or supplementary local performance indicators [38], whereas tax relief applies to taxpayers rated Grade A or B in the national grading of key industries [8]. Whether local grading results can be used for tax relief is not yet clear.

5. Policy Recommendations

Ex ante studies have estimated the effects of VOC taxation under alternative tax levels and scopes [10, 11]. Once the pilot is running, its operational data will also allow ex post evaluation. For example, the Comprehensive Demonstration Cities for Energy Conservation and Emission Reduction Fiscal Policies, a fiscal demonstration programme launched in China in 2011, has been evaluated with city-level panel data in a quasi-natural experimental design, and its effects were found to differ across regions, city sizes and administrative levels [40]. Building such evaluation into the VOC tax pilot from the outset would support the following recommendations.

(1) Issue supporting calculation methods promptly and clarify verification feedback rules. For each source category, the rules should specify activity levels, VOC content, capture and removal efficiencies and the treatment of missing data, and harmonise the data used in enterprise ledgers, permit implementation reports and tax returns. For source categories with more than one statutory quantification route, pilot data can be used to study the conditions under which parameters should be reviewed or methods adjusted when persistent significant deviations or distorted key parameters are found.

(2) Evaluate simplified administration for small emitters on the basis of pilot data. Filing costs, verification workload and tax payable should be recorded for enterprises of different sizes, and burdens should be reduced primarily through simplified filing, lower reporting frequency and reuse of permit data.

(3) Carry out provincial tax amount assessments and evaluate differentiated arrangements prudently. Provincial tax amounts should be determined using local industrial emission inventories and data from typical enterprises to estimate the distribution of tax burdens, emission reduction effects and industrial impacts under different tax levels. Once the boundary of provincial authority has been clarified, the potential emission reduction effects and changes in enterprise tax burdens of area- and period-differentiated price signals should be evaluated comprehensively.

(4) Conduct a targeted review of VOC-related permit information before implementation. Focusing on the eight pilot industries, the review should check information on production facilities, raw and auxiliary materials, VOC emission links, control facilities and emission source categories, and information that should have been recorded but was omitted, or that clearly deviates from actual production, should be corrected through the prescribed procedures.

(5) Clarify the rules for applying performance grades in taxation. The rules should specify the grading results eligible for tax relief, the alignment between grading validity periods and tax periods, the timing of changes to relief after a grade is adjusted or revoked, and the channels for transmitting grading information, so that environmental management and tax administration use consistent grading criteria.

6. Conclusions

(1) Foreign VOC economic instruments can be grouped into three approaches: emission-stage charging, supply-side taxation and investment-side incentives. The SCAQMD and the Taiwan region of China charge according to emissions, which sends a direct price signal but depends on emission quantification and verification. Switzerland taxes at the import and domestic production stages and uses the commitment procedure and annual VOC balances to reconnect upstream taxation with actual releases. Japan relies mainly on legal regulation and voluntary reduction, supplemented by tax and financing support for abatement investment. The performance of each system depends mainly on its operating rules for tax base identification, emission quantification, filing verification and incentive design.

(2) China's Pilot Measures share comparable mechanisms with foreign systems in emission-stage taxation, source-specific quantification and deemed assessment. Their institutional innovations—deduction of 18 individual species after source-category aggregation, separate taxation of VOCs

as a whole, and performance-based tax relief—connect the new tax with the existing environmental protection tax, pollutant discharge permitting and performance grading systems.

(3) The pilot has entered an implementation preparation period in which the institutional framework is settled but supporting rules are pending. Source-category calculation methods and verification feedback, administration of small emitters, provincial tax amounts, permit-based taxpayer identification and the tax application of performance grades are the areas that need to be improved first, before and after formal implementation, as they directly determine whether taxable emissions can be calculated and what compliance and administrative costs taxpayers and tax authorities will bear. More broadly, the comparison suggests that the effectiveness of an emission-based VOC tax depends less on the nominal tax rate than on the quality of the supporting rules for quantification, verification and incentive design.

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