THE EFFECTIVENESS OF CARBON TAXES AND TRADING SCHEMES TO REDUCE CO2 EMISSIONS

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Abstract

Carbon taxes and trading schemes are pivotal instruments in the fight against climate change, aimed at reducing CO2 emissions by providing economic incentives for emission reductions. This paper examines the effectiveness of these mechanisms in various contexts, analyzing their design, implementation, and outcomes across different regions and industries. Carbon taxes impose a direct cost on carbon emissions, encouraging businesses and consumers to reduce their carbon footprint, while cap-and-trade systems set a limit on total emissions and allow for the trading of emission permits. The analysis highlights the strengths and weaknesses of each approach, including their economic impacts, environmental effectiveness, and equity considerations. The findings suggest that both carbon taxes and trading schemes can significantly contribute to emission reductions when designed with careful consideration of local economic conditions and social implications. The paper concludes with recommendations for policymakers to enhance the effectiveness of these tools in achieving climate targets.

Keywords: carbon tax, cap-and-trade, CO2 emissions, climate change, emission reduction, environmental policy

I. Introduction

Climate change represents one of the most pressing challenges of our time, driven primarily by anthropogenic greenhouse gas (GHG) emissions. The escalating impacts of climate change—ranging from extreme weather events to rising sea levels—underscore the urgency for effective policy measures to mitigate these effects. Economic theories regarding externalities provide a foundational framework for understanding the role of market failures in exacerbating environmental degradation. In the early 20th century, economist Arthur Pigou introduced the concept of externality, which refers to costs or benefits resulting from an action that are not accounted for by the producer. For instance, the combustion of fossil fuels not only generates energy but also releases harmful emissions, imposing significant social costs on society that far exceed the private costs incurred by producers.

As the global community grapples with the challenges posed by climate change, policymakers have increasingly turned to market-based mechanisms, such as carbon taxes and emissions trading systems (ETSs), as strategies for reducing GHG emissions. These tools are designed to internalize the external costs associated with carbon emissions, thereby creating economic incentives for businesses and consumers to shift towards cleaner alternatives. The Pigovian tax, named after Pigou, is one such approach that aims to align private costs with social costs, thereby promoting more efficient resource allocation and encouraging sustainable practices.

Despite their theoretical appeal, the implementation of carbon taxes and ETSs has sparked considerable debate regarding their effectiveness, equity, and economic impacts. Critics argue that the costs associated with these policies can disproportionately burden vulnerable populations and

that the actual reductions in emissions may fall short of established targets. Conversely, proponents assert that when designed and implemented correctly, these policies can drive significant reductions in GHG emissions while fostering innovation in clean technologies.

This study aims to critically examine the effectiveness of carbon taxes and emissions trading schemes in mitigating climate change by reviewing contemporary empirical and theoretical research on these market-based instruments. By investigating their design, implementation, and outcomes, the paper seeks to provide a comprehensive understanding of how these policies can be optimized to achieve climate goals. The following sections will outline the economic theory underpinning these instruments, discuss their design considerations, evaluate their practical implementation, and analyze their effectiveness in reducing emissions and their broader economic implications. Ultimately, this research aspires to identify best practices and inform policy design that enhances global efforts to combat climate change.

The economic and environmental effects of climate change and associated policies have emerged as a significant topic of international policy discussions over recent decades. In 2015, at the United Nations (UN) Climate Change Conference (COP21), 196 parties reached a consensus on a legally binding global treaty, known as the Paris Agreement (The Paris Agreement | UNFCCC). This agreement primarily aims to limit the increase in global average temperature to well below 2°C above pre-industrial levels while striving to keep the rise to 1.5°C. However, a 2023 report by UNFCCC indicates that the world is currently not on track to meet the goals set forth in the Paris Agreement, highlighting the urgent need for additional action to reduce global greenhouse gas (GHG) emissions and achieve net-zero emissions by 2050. This shortfall is evident despite the introduction of over 70 carbon-related policies by 2024, which include 39 carbon taxes and 36 emissions trading systems (ETSs) implemented across various national and subnational jurisdictions worldwide. This situation raises critical questions about the effectiveness of these policies: Are carbon taxes and ETSs effective in curbing GHG emissions? Which of the two policies has yielded the best results? Can the effectiveness of these policies be enhanced? What are the economic implications of such policies? To address these inquiries, this study provides a thorough review of contemporary empirical and theoretical research analyzing the impact of the two primary market-based instruments—carbon taxes and ETSs—on global environmental and economic conditions.

A carbon tax is a price-control mechanism that internalizes the external costs associated with carbon emissions by imposing a direct charge on emissions. In contrast, an ETS is a quantity-control mechanism aimed at reducing carbon emissions by establishing a cap on the total allowable GHG emissions for each period. Both systems are designed to increase the relative cost of producing goods that emit GHGs compared to those that do not, thereby decreasing the incentive to produce GHG-emitting products. Although other ad valorem taxes, such as fuel or value-added taxes, may also influence the relative pricing of GHG emissions, these taxes are primarily implemented to generate government revenue rather than to reduce emissions. Consequently, few studies have attempted to quantify the environmental and economic impacts of such ad valorem taxes across different countries. This review, therefore, focuses on the effects of carbon taxes and ETSs, specifically emphasizing their role in reducing GHG emissions rather than merely increasing government revenue. By conducting a systematic literature review of empirical outcomes and theoretical insights regarding the impact of these instruments on environmental and economic conditions, this study aims to synthesize research findings in both physical and economic sciences. This work also integrates and updates existing information about the environmental impacts of carbon pricing mechanisms and their economic consequences. A key distinction from previous reviews is that this study comprehensively covers both carbon taxation and ETSs, analyzing their relative effects rather than examining a single policy tool in isolation. By

doing so, we aim to identify best practices and inform policy design that can ultimately enhance global efforts to combat climate change.

The remainder of this paper is organized as follows: Section 2 outlines the economic theory underlying carbon tax and ETS policies. Section 3 discusses the design considerations for each policy. Section 4 explores the practical implementation of these policies. Section 5 assesses the effectiveness of the policies in reducing emissions and their economic impacts. Sections 6 and 7 compare carbon taxes and ETSs and discuss potential policy integration. Finally, Section 8 summarizes our conclusions and offers suggestions for future research.

II. Methods

This study utilizes three specific methods to evaluate the effectiveness of carbon taxes and emissions trading systems (ETSs) in reducing greenhouse gas (GHG) emissions:

1. **Systematic Literature Review**:
   - A systematic literature review was conducted to collect and analyze empirical studies and theoretical papers focusing on carbon taxes and ETSs. The review involved searching databases such as JSTOR, Google Scholar, and ScienceDirect for relevant articles published from 2000 to 2024.
   - The inclusion criteria prioritized peer-reviewed articles that assess the impact of these policies on GHG emissions and their economic implications. Studies were categorized based on their findings related to effectiveness, economic impact, and social equity.
   - This method allowed for the identification of trends, common themes, and gaps in existing research, enabling a comprehensive understanding of the current state of knowledge regarding carbon pricing mechanisms.
2. **Case Study Analysis**:
   - The study analyzed specific case studies from countries and regions that have implemented carbon taxes and ETSs, such as Sweden, the European Union, and California.
   - Each case study focused on the design and implementation of the policy, the context in which it was applied, and the measurable outcomes in terms of GHG emissions reductions and economic effects.
   - This method provided practical insights into the real-world application of carbon pricing mechanisms, illustrating the challenges and successes experienced in different geographical and political contexts.
3. **Comparative Policy Analysis**:

A comparative analysis was performed to evaluate the effectiveness of carbon taxes versus ETSs. This involved assessing various dimensions, such as:

- **Emission Reduction Targets**: Comparing the actual GHG reductions achieved by each policy type.
- **Economic Impact**: Analyzing how each policy affects economic growth, industry competitiveness, and employment levels.
- **Social Equity**: Evaluating the distributional impacts of these policies on different socioeconomic groups.

This method enabled the identification of best practices and lessons learned from each policy approach, facilitating recommendations for enhancing the effectiveness of carbon pricing mechanisms.

By employing these methods, the study aims to provide a detailed analysis of how carbon taxes and emissions trading systems function in practice and their effectiveness in addressing climate change.

III. Results

In the 20th century, economist Arthur Pigou first introduced the concept of externality, which refers to costs or benefits that arise from an action but are not borne by the producer of that action. A clear example of this is climate change, where energy use and industrial processes contribute to anthropogenic climate change through greenhouse gas (GHG) emissions, representing a negative externality. In such scenarios, the marginal social cost incurred by society is significantly greater than the marginal private cost of production experienced by a firm, leading to a market failure where the optimal quantity of production exceeds the socially optimal quantity. Pigou proposed that policymakers could rectify this market failure by imposing a tax on market activities that reflects the social damage caused, known as a Pigovian tax.

Figure 1 illustrates a typical Pigouvian tax, where the private marginal benefit of consuming goods declines as the quantity demanded increases, while the private marginal cost of supplying goods rises with the quantity supplied. An efficient market achieves equilibrium when private marginal benefits equal private marginal costs, occurring at the quantity q_{market} and price p_{market} shown in the figure. However, when a good's consumption generates negative externalities—such as air pollution from fossil fuel consumption—the social marginal cost reflects the marginal external cost in addition to the private marginal cost of supply. A "social marginal cost" line represents this cumulative cost, illustrating how the externality can be internalized by imposing a tax on the purchase of the good (indicated by the line representing private marginal cost plus tax). The tax rate is set to equal the marginal external cost, aligning with the social optimum. This taxation shifts the market equilibrium to the optimal point $q_{optimum.}$

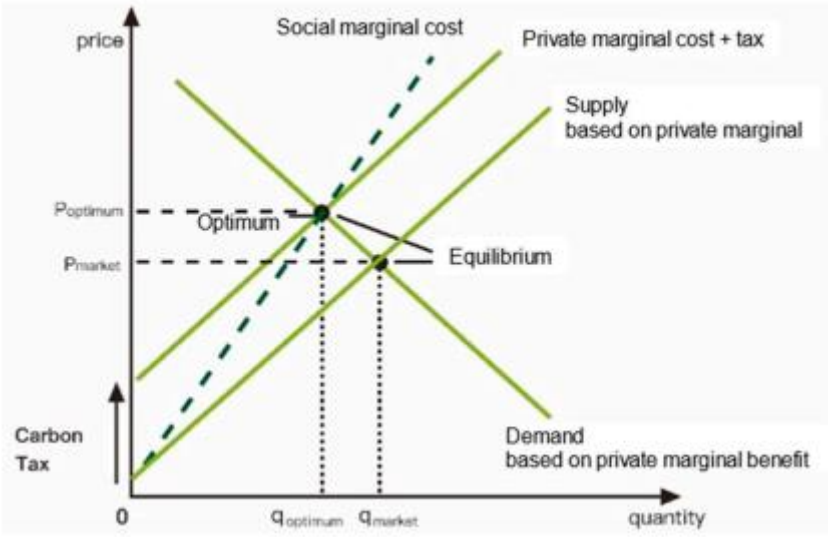

Figure 1: *Pigouvian tax*

Carbon taxes, as a first-best or optimal solution to address the negative externalities associated with anthropogenic carbon dioxide emissions, have become a preferred policy in many countries pursuing ambitious climate goals. However, these taxes face criticism. Early theoretical and practical discussions regarding the identification of social costs, as well as the costs of misallocation linked to market intervention versus maintaining the status quo, were explored by prominent 20th-century economists such as Coase, Hayek, Ostrom, and Baumol. More recently, political economy literature has associated carbon taxes with climate capitalism, while narrow, discipline-specific perspectives have led to the emergence of technocentric and economistic

viewpoints.

The theoretical foundations of emissions trading systems (ETS) can be traced back to the research of Nobel Prize laureate Ronald Coase. Coase posited that when trade in externalities, such as greenhouse gas (GHG) emissions, is feasible and transaction costs are low, bargaining among parties will lead to a Pareto efficient outcome, regardless of the initial distribution of property rights. This principle, now known as the Coase Theorem, suggests that government intervention can mitigate market failures arising from negative externalities by clearly defining property rights.

As depicted in Fig. 2, when a cap on emissions is established, it imposes a hard limit on the market supply, rendering the supply curve inelastic and unresponsive to price fluctuations as seen in traditional supply-demand models. The new equilibrium is determined by the cap, resulting in a $q_{constrained}$ and an increase in the price $p_{optimum/}$

Building on these principles, Dales introduced the concept of property rights within the context of pollution control in 1968 by formalizing an Emissions Trading Program, which has since become the foundation of contemporary ETSs. Under this framework, entities granted the right to emit GHGs can do so, provided they comply with specific legal conditions. Legally, emissions rights are treated as limited-use rights associated with environmental resources, conceptualizing the environment as a tradable commodity with the government as the ultimate proprietor.

In this system, the government allocates a fixed quantity of emissions rights to firms, permitting them to emit GHGs during their production processes. Moreover, by facilitating the trading of these rights under regulatory conditions, emissions effectively become a tradable commodity. Firms facing higher marginal costs for pollution can purchase emissions rights from those with lower emission costs. Consequently, this cap-and-trade market structure fosters a Pareto-optimal allocation, minimizing total emissions costs while capping the overall volume of GHG emissions produced in the market.

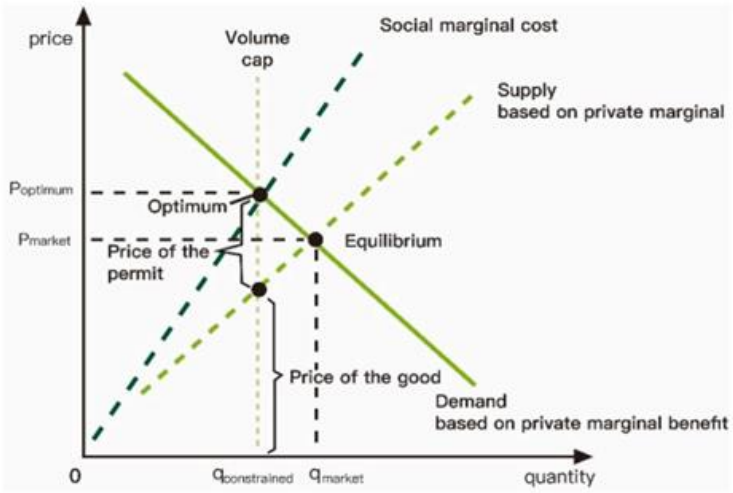

Figure 2: *Coasian model*

IV. Discussion

After determining the emissions cap, policymakers must decide how to allocate pollution permits under the emissions trading system (ETS). There are two primary allowance allocation schemes used to date: free allocation and public auction.
The main advantages of free allocation include zero transaction costs and the potential for equitable distribution of permits, resulting in low resistance to execution and ease of

implementation. This method has often been employed during the initial pilot stages of ETSs. Common approaches for permit distribution include:

- Grandfathering: Allocating permits based on historical emissions.
- Output-Based Allocation: Assigning permits according to current emissions.
- Fixed-Sector Benchmarking: A combination of historical and current emissions for allocation.

However, research indicates that grandfathering may undermine ETS efficiency due to inadequate financial support for system operation. Consequently, some studies have suggested employing formal pricing and auction methods to improve the effectiveness of carbon emissions trading.

Auctions provide several advantages over free allocation:

1. Reduced Disputes: Auctions minimize conflicts between stakeholders that can arise from free distribution, aligning with fairness and justice principles appropriate for ETSs.
2. Increased Government Revenue: By auctioning permits, governments can generate additional revenue, which can be reinvested in environmental initiatives or used to offset costs associated with the transition to a low-carbon economy.
3. Incentives for Innovation: The auction pricing mechanism encourages firms to enhance their technical capabilities and innovate towards low-emission technologies, thereby contributing to overall emissions reductions.

By considering these allocation strategies, policymakers can better design ETSs to achieve their environmental goals while promoting equity and economic efficiency.

This review indicates that many studies have arrived at similar conclusions regarding the absolute advantages and disadvantages of carbon taxes and emissions trading systems (ETSs) in terms of emissions reduction. Consequently, the current debate has shifted towards comparing the implementation of carbon taxes and ETSs, as summarized in Table 1. This shift is driven by the necessity to examine the relative benefits of each approach concerning emissions reduction, cost savings, economic efficiency, technological advancements, political acceptance, and stakeholder engagement.

Theoretical research suggests that the impacts of these two mechanisms should align when information is complete, transaction costs are negligible, and price controls are set at the intersection of the marginal costs and benefits of emissions reduction. However, in practice, information is rarely complete, and transaction costs typically exceed zero. Therefore, while both mechanisms can effectively reduce emissions, their associated costs and incentive effects logically differ.

Given the significant establishment, implementation, and administrative costs associated with ETSs, it is not surprising that carbon taxes tend to incur lower costs in these areas, making them more accessible during the initial stages of implementation. However, carbon taxes increase production costs for businesses, which can constrain profit margins and influence optimal decision-making. Firms may also pass the tax burden onto downstream producers and consumers by raising prices, potentially leading to inflation and negatively affecting overall economic conditions. Additional critiques of carbon taxes include the challenges of determining an optimal tax rate and policymakers' delays in responding to current market conditions.

Despite the benefits of carbon taxes, evidence indicates that ETSs may have a greater impact on emissions reduction and innovation incentives. Furthermore, ETSs can lower information costs and enhance the competitiveness of polluters. According to Murray et al., cap-and-trade systems are more welfare-enhancing than carbon taxes if mechanisms such as storage, banking, or borrowing of emissions rights are permitted. The ETS also clarifies overall emissions abatement goals and facilitates emissions management across international borders, making it better suited

for long-term implementation. Additionally, once the total emissions allowance is established, the emissions reduction target can be more readily adjusted to align with current market conditions.

	Advantages	Disadvantages
Carbon Taxes	• Lower establishment, implementation, and administrative costs	•Higher production cost •Cause inflation and worsen the overall economic situation •Optimal tax rate is difficult to determine •Takes time for policymakers to respond to current market conditions
ETSs	•Greater emission reduction effect and incentive to innovate •Lowers information costs •Enhance the competitiveness of polluters •Cap-and-trade system is more welfare-enhancing •Better suited in the long run •More easily adjusted to current market conditions	•Larger establishment, implementation, and administrative costs •Lack price transparency

Table 1: *Comparisons between carbon taxes and ETSs.*

Nevertheless, while ETSs offer key advantages over carbon taxes, it is important to note that their establishment, implementation, and administrative costs are relatively high. Furthermore, the induced price from the carbon cap is not always transparent, which can complicate planning for firms and create uncertainty regarding overall emissions reduction costs. Even the EU ETS, one of the largest globally, has faced price volatility due to excessive quota distribution and periods of economic downturn. Therefore, it is crucial to closely monitor ETSs to ensure their effectiveness, efficiency, and sustained capacity to reduce emissions.

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