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Can the carbon cap-and-trade and government subsidies drive carbon abatement and mitigate environmental impacts?

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Abstract. Global governments and industrial enterprises have increasingly prioritized carbon mitigation and ecological conservation, prompting the rollout of diverse regulatory and fiscal tools to drive manufacturing decarbonization. This paper establishes a two-echelon low-carbon supply chain game framework to quantify how distinct policy interventions reshape manufacturers' clean technology investment and emission-cutting behaviors. Core analytical findings are as follows: When consumers exhibit strong green consumption preferences, the carbon cap-and-trade regime delivers maximized profitability for both upstream manufacturers and downstream retailers, alongside superior carbon reduction performance and minimized ecological harm. Nevertheless, fiscal subsidies targeting manufacturers primarily serve profit-maximizing motives rather than robust emission abatement, which implies trading mechanisms may underperform in curbing industrial carbon outputs. Social welfare dynamics hinge on the intensity of public low-carbon demand: emission trading outperforms alternatives once consumer green preference crosses a critical threshold, while manufacturer-specific fiscal incentives yield more favorable aggregate social welfare in most practical scenarios.

Keywords: carbon cap-and-trade, government subsidy, clean technology, environmental impact, social welfare

1. Introduction

Sustained rapid industrial expansion has triggered severe ecological crises, ranging from atmospheric contamination to stratospheric ozone layer depletion, steadily degrading planetary ecological balance. Governments and corporate stakeholders alike have heightened awareness of these environmental risks, spurring widespread legislative and policy efforts to constrain industrial carbon discharges [1]. The *Paris Agreement*, ratified by 195 sovereign nations, exemplifies this global shift by mandating coordinated cross-border carbon reduction roadmaps [2].

Beyond international climate accords, nations worldwide have enacted targeted carbon regulatory instruments, among which carbon cap-and-trade systems stand out as a flagship market-based policy (See Figure 1). The European Union Emissions Trading System (EU-ETS) serves as a benchmark instance, covering over 30 member territories and regulating roughly 45% of the bloc's aggregate industrial carbon emissions.

Complementary subsidy schemes have also been deployed to offset manufacturers' green transformation expenses and accelerate clean technology uptake. Representative initiatives include Australia's Clean Technology Investment Program, which covers half of enterprises' low-carbon innovation outlays, and Canada's national decarbonization fund that provides matching financial support for emission-reduction corporate projects [3, 4]. These fiscal measures profoundly alter manufacturers' willingness to invest in carbon abatement.

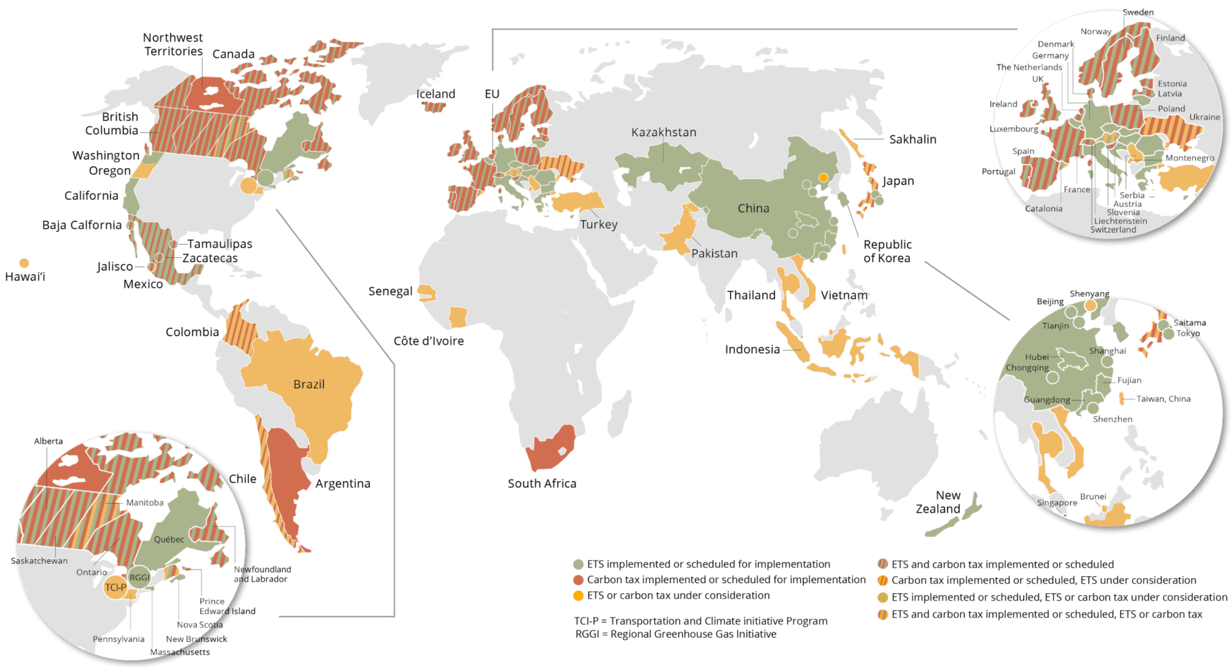

Figure 1. Countries and regions that implemented carbon cap-and-trade policies

This research investigates the effects of various government policies on manufacturers' carbon abatement and social welfare. It specifically examines three policy scenarios: *No-Government Policy*, *Carbon Cap-and-Trade*, and *Government Subsidy Policy*. The study aims to address several critical questions: How do these distinct policies influence manufacturers' carbon abatement strategies and the equilibrium decisions of stakeholders? Which of the policies promotes improved carbon emission reductions and the profitability of stakeholders? Additionally, it explores the impacts of different government interventions on social welfare and the environment, highlighting the interplay between policy measures and their broader societal effects?

2. Literature review

2.1. Government subsidy

The impact of the social environment has been significantly studied, yielding notable research results[5-8]. Yang et al. [9] constructed a competitive game model and analyzed the impact of government subsidies on technological improvements in enterprises. The evidence confirms such fiscal tools effectively resolve the prisoner's dilemma in industrial decarbonization and lift overall social welfare. Similar to Bian et al. [5], Xu et al. [10] also studied the impact of carbon taxes and subsidies on manufacturers' carbon reduction and social welfare. However, their results indicate that government subsidy policies do not harm social welfare. Further extending this line of inquiry, other scholars have scrutinized the differential impacts of various subsidy programs on operational decisions, carbon mitigation, and social welfare [11, 12].

2.2. Carbon cap-and-trade policy

Market-based carbon trading mechanisms are widely recognized as effective drivers of industrial decarbonization, attracting extensive scholarly scrutiny regarding their impacts on corporate operational choices and emission-cutting inputs [13-16]. Feng et al. [2] analyzed the impact of joint replenishment on participants' profits under carbon emission trading policies and designed an altruistic allocation rule. They demonstrated that retailers do not always tend to transfer excess carbon allowances to other retailers. Kuiti et al. [17] investigated supply chain equilibrium under carbon pricing rules, demonstrating elevated carbon allowance transaction prices expand market supply and strengthen firms' corporate social responsibility commitments. Supplementary studies further unpack carbon trading's spillover effects on supply chain coordination, circular remanufacturing, distribution channel optimization, and multi-layered environmental performance [18-21].

2.3. Clean technology

Several researchers have also explored the impact of clean technology on reducing corporate carbon emissions and its effects on the social environment [22-24]. Ma et al. [25] explored the impact of different subsidy programs on the adoption of clean technologies by enterprises. Their research results indicate that subsidy programs play a positive role in promoting the adoption of clean technologies by enterprises. Shi et al. [26] analyzed three different scenarios of clean technology investment in a competitive environment. Shen et al. [27] studied the impact of adopting clean technologies on corporate production operations under a carbon tax in sustainable supply chains. They demonstrated that under carbon tax policies, the increase in the adoption of clean technologies contributes to enhancing consumer welfare and the greening of products. Other recent contributions explore how state intervention shapes corporate clean tech adoption decisions [28, 29].

3. Model

This analysis constructs a vertical supply chain consisting of a single upstream manufacturer and a single downstream retailer (follower). The manufacturer develops low-carbon commodities and wholesales goods to retailers at a unit wholesale price w; retailers subsequently set the final retail price p and sell finished products to end consumers. The model assumes consumers hold intrinsic preference for eco-friendly merchandise, translating into greater willingness-to-pay for low-carbon items and expanding market demand. Assuming manufacturers produce low-carbon products with a unit production cost of c and an initial carbon emission of e_o [30]. To lower product carbon footprints, firms invest in clean technical renovation, with quadratic investment cost function $C(e) = \frac{ke^2}{2}$, where e denotes the carbon reduction level of the clean technology, k represents the clean technology investment cost coefficient for manufacturers. This quadratic cost function is extensively used in the literature [31, 32]. The linear market demand function is defined as $D = a - p + \beta e$, where a denotes the basic market demand, β indicates the low-carbon preference of consumers, and e represents the level of carbon reduction when manufacturers adopt clean technologies.

4. Results

4.1. Without government policy

This subsection solves supply chain equilibria absent any state climate regulation to isolate the independent impacts of manufacturers' clean technology adoption on carbon mitigation and socio-environmental outcomes. Under unregulated market conditions, the demand function simplifies to: $D^N = a - p + \beta e$.

Corresponding profit expressions for retailers and manufacturers are formulated as follows (See equation (1)):

$$\pi_R^N = (p-w)(a-p+\beta e), \pi_M^N = (w-c)(a-p+\beta e) - ke^2/2 \tag{1}$$

This study derives the closed-form equilibrium solutions summarized in Proposition 1.

Proposition 1. Under unregulated market conditions, the authors derive the equilibrium results for the manufacturer and the retailer as follows: $w^{N*} = \frac{2ak+2ck-c\beta^2}{4k-\beta^2}$, $e^{N*} = \frac{(-a+c)\beta}{-4k+\beta^2}$, $p^{N*} = \frac{-3ak+c(-k+\beta^2)}{-4k+\beta^2}$, $q^{N*} = \frac{(a-c)k}{4k-\beta^2}$, $\pi_R^{N*} = \frac{(a-c)^2k^2}{(-4k+\beta^2)^2}$, $\pi_M^{N*} = \frac{(a-c)^2k}{8k-2\beta^2}$.

Differential comparative statics yield the deductions outlined in Corollary 1: (1) $\frac{\partial w^{N*}}{\partial k} < 0$, $\frac{\partial w^{N*}}{\partial \beta} > 0$; $\frac{\partial e^{N*}}{\partial k} < 0$, $\frac{\partial e^{N*}}{\partial \beta} > 0$; $\frac{\partial p^{N*}}{\partial k} < 0$, $\frac{\partial p^{N*}}{\partial \beta} > 0$; $\frac{\partial q^{N*}}{\partial k} < 0$, $\frac{\partial q^{N*}}{\partial \beta} > 0$, (2) if $k > \frac{\beta^2}{4}$, $\frac{\partial \pi_R^{N*}}{\partial k} < 0$, $\frac{\partial \pi_M^{N*}}{\partial k} < 0$, otherwise, $\frac{\partial \pi_R^{N*}}{\partial k} > 0$, $\frac{\partial \pi_M^{N*}}{\partial k} > 0$. If $k > \frac{\beta^2}{4}$, $\frac{\partial \pi_R^{N*}}{\partial \beta} > 0$, $\frac{\partial \pi_M^{N*}}{\partial \beta} > 0$, otherwise, $\frac{\partial \pi_R^{N*}}{\partial \beta} < 0$, $\frac{\partial \pi_M^{N*}}{\partial \beta} < 0$.

Elevated consumer green preference expands potential market demand, motivating manufacturers to raise wholesale prices and amplify clean tech investment to lift carbon reduction intensity; consumers also accept higher retail price points for eco-friendly goods, further lifting equilibrium output. Conversely, higher clean tech marginal costs suppress manufacturers' decarbonization incentives, depressing all pricing, output and carbon reduction metrics. When low-carbon technical renovation carries steep marginal costs, rising investment expenses erode profit margins for both supply chain tiers. Under low-cost clean tech conditions, greater green preference and lower renovation costs jointly boost profitability for manufacturers and retailers.

Following the social welfare framework established by Krass et al. [33], aggregate social welfare is defined as: $SW = \pi_M + \pi_R + CS - Exp - EI$, where π_M represents manufacturer profits under different policies, π_R denotes retailer profits under different policies, CS stands for consumer surplus, Exp indicates government expenditures under different policies, EI denotes the social-environmental impact under different scenarios. Furthermore, ϕ converts physical carbon pollution into monetary environmental losses. Therefore, this study can obtain the equilibrium results for consumer surplus, environmental impact and government expenditure under scenario N (see Proposition 2).

Proposition 2. Substituting unregulated market equilibria into the social welfare function yields: $CS^{N*} = \frac{(a-c)^2k^2}{2(-4k+\beta^2)^2}$, $Exp^{N*} = 0$, $EI^{N*} = \frac{(a-c)^2k\beta\phi}{(-4k+\beta^2)^2}$, $SW^{N*} = \frac{(a-c)^2k(7k-\beta(\beta+2\phi))}{2(-4k+\beta^2)^2}$.

4.2. Carbon cap-and-trade policy

Under carbon allowance trading rules, state authorities fix each manufacturer's baseline free emission quota G, while market transactions determine the spot price p_t of extra carbon allowances. Firms purchase additional quotas if actual emissions exceed allocated limits, or sell surplus allowances to generate extra revenue. Retailers' profit function remains unchanged from Scenario N, while manufacturers' profit expression incorporates carbon trading cash follows (See equation (2)):

$$\pi_R^C = (p-w)(a-p+\beta e),\ \pi_M^C = (w-c)(a-p+\beta e) + p_t(G-(e_o-e)q) - \frac{ke^2}{2} \tag{2}$$

Proposition 3. Equilibrium outcomes under carbon cap-and-trade regulation are: $w^{C*} = \frac{a(2k-t(t+\beta))-(c+e_o t)(-2k+\beta(t+\beta))}{4k-(t+\beta)^2}$, $e^{C*} = \frac{(a-c-e_o t)(t+\beta)}{4k-(t+\beta)^2}$, $p^{C*} = \frac{a(3k-t(t+\beta))-(c+e_o t)(-k+\beta(t+\beta))}{4k-(t+\beta)^2}$, $q^{C*} = \frac{k(a-c-e_o t)}{4k-(t+\beta)^2}$, $\pi_R^{C*} = \frac{k^2(-a+c+e_o t)^2}{(-4k+(t+\beta)^2)^2}$, $\pi_M^{C*} = \frac{a^2k+c^2k+2cke_o t-2ak(c+e_o t)+t(ke_o{}^2t+G(8k-2(t+\beta)^2))}{8k-2(t+\beta)^2}$.

Inserting these solutions into the social welfare identity delivers Proposition 4's socio-environmental equilibria.

Proposition 4. In the non-government subsidy scenario, the authors substitute the equilibrium results of the stakeholders into the social welfare function when considering the adoption of clean technologies by manufacturers. This study has the following equilibrium results:

$CS^{C*} = \frac{k^2(-a+c+e_o t)^2}{2(-4k+(t+\beta)^2)^2}$, $EI^{C*} = \frac{k(-a+c+e_o t)^2(t+\beta)\phi}{(-4k+(t+\beta)^2)^2}$, $SW^{C*} = \frac{3k^2(-a+c+e_o t)^2}{2(-4k+(t+\beta)^2)^2} + \frac{a^2k+c^2k+2cke_o t-2ak(c+e_o t)+t(ke_o{}^2t+G(8k-2(t+\beta)^2))}{8k-2(t+\beta)^2} - \frac{k(-a+c+e_o t)^2(t+\beta)\phi}{(-4k+(t+\beta)^2)^2}$;

Corollary 2: (1) $\frac{\partial e^{C*}}{\partial t} > 0$, $\frac{\partial e^{C*}}{\partial \beta} > 0$; $\frac{\partial p^{C*}}{\partial \beta} > 0$, $\frac{\partial p^{C*}}{\partial t} > 0$, (2) if $t < \frac{-\beta^2(a-c+m\beta)+2k(a-c+2m\beta)+2\sqrt{k(k-\beta^2)(-4km^2+(a-c+m\beta)^2)}}{2km+\beta(a-c+m\beta)}$, $\frac{\partial w^{C*}}{\partial t} > 0$, otherwise, $\frac{\partial w^{C*}}{\partial t} < 0$, when $k > \frac{t(t+\beta)^2}{4\beta}$, $\frac{\partial w^{C*}}{\partial \beta} > 0$.

Higher consumer green preference expands demand for eco-friendly goods, incentivizing manufacturers to scale up carbon reduction investments and raise retail price points. Rising carbon allowance prices amplify the marginal gains from emission cuts, further lifting manufacturers' optimal decarbonization intensity. Carbon trading prices exert non-monotonic impacts on wholesale pricing: below the critical threshold, higher allowance prices push manufacturers to raise wholesale prices to offset decarbonization expenses. Once carbon prices exceed the threshold, steep emission-cutting costs suppress manufacturers' ability to mark up wholesale prices. Green consumer preference only drives wholesale price growth when clean technology renovation costs remain sufficiently low.

4.3. Manufacturer's subsidy policy

Under this fiscal intervention regime, governments cover a share r of manufacturers' low-carbon technical renovation expenditures to lower marginal decarbonization costs and stimulate emission reduction investment. Retailer profit functions remain identical to prior scenarios, while manufacturers' investment cost burden is reduced proportionally (See equation (3)):

$$\pi_R^S = (p-w)(a-p+\beta e), \pi_M^S = (w-c)(a-p+\beta e) - k(1-r)\frac{e^2}{2} \tag{3}$$

Proposition 5. Equilibrium pricing, output and carbon reduction metrics under subsidy r: $w^S(r) = \frac{-2ak-2ck+2akr+2ckr+c\beta^2}{-4k+4kr+\beta^2}$, $e^S(r) = \frac{(-a+c)\beta}{4k(-1+r)+\beta^2}$, $p^S(r) = \frac{(3a+c)k(-1+r)+c\beta^2}{4k(-1+r)+\beta^2}$, $q^S(r) = \frac{(a-c)k(-1+r)}{4k(-1+r)+\beta^2}$, $\pi_R^S(r) = \frac{(a-c)k(-1+r)}{4k(-1+r)+\beta^2}$, $\pi_M^S(r) = \frac{(a-c)^2k(-1+r)}{8k(-1+r)+2\beta^2}$.

Proposition 6. Socio-environmental equilibrium outcomes under subsidy r: $CS^S(r) = \frac{(a-c)^2k^2(-1+r)^2}{2(4k(-1+r)+\beta^2)^2}$, $EXP^S(r) = \frac{(a-c)^2kr\beta^2}{2(4k(-1+r)+\beta^2)^2}$, $EI^S(r) = -\frac{(a-c)^2k(-1+r)\beta\phi}{(4k(-1+r)+\beta^2)^2}$, $SW^S(r) = \frac{(a-c)^2k(7k(-1+r)^2-\beta(\beta-2(-1+r)\phi))}{2(4k(-1+r)+\beta^2)^2}$.

Governments optimize subsidy r to maximize aggregate social welfare. Solving the first-order welfare maximization condition yields the theoretical optimal subsidy intensity: $r^* = \frac{3k\beta-4k\phi-\beta^2\phi}{k(7\beta-4\phi)}$. Substituting this welfare-maximizing subsidy rate back into all equilibrium expressions delivers Proposition 6's optimal supply chain and socio-environmental solutions under fiscal subsidies.

Proposition 7. Full equilibrium results at the socially optimal subsidy intensity r^*: $w^{S*} = \frac{8ak+8ck-7c\beta^2+2(a+3c)\beta\phi}{16k+\beta(-7\beta+8\phi)}$, $e^{S*} = \frac{(a-c)(7\beta-4\phi)}{16k+\beta(-7\beta+8\phi)}$, $p^{S*} = \frac{4ck+c\beta(-7\beta+5\phi)+3a(4k+\beta\phi)}{16k+\beta(-7\beta+8\phi)}$,

$q^{S*} = \frac{(a-c)(4k+\beta\phi)}{16k+\beta(-7\beta+8\phi)}$, $\pi_R^{S*} = \frac{(a-c)^2(4k+\beta\phi)^2}{(16k+\beta(-7\beta+8\phi))^2}$, $\pi_M^{S*} = \frac{(a-c)^2(4k+\beta\phi)}{32k+2\beta(-7\beta+8\phi)}$, $CS^{S*} = \frac{(a-c)^2(4k+\beta\phi)^2}{2(16k+\beta(-7\beta+8\phi))^2}$, $EXP^{S*} = \frac{(a-c)^2(7\beta-4\phi)(-3k\beta+4k\phi+\beta^2\phi)}{2(16k+\beta(-7\beta+8\phi))^2}$, $EI^{S*} = \frac{(a-c)^2(7\beta-4\phi)\phi(4k+\beta\phi)}{(16k+\beta(-7\beta+8\phi))^2}$, $SW^{S*} = \frac{(a-c)^2(7k+\phi^2)}{32k+2\beta(-7\beta+8\phi)}$.

5. Numerical study

Numerical simulations are deployed to intuitively verify all analytical propositions and visualize how core parameters shape supply chain profit, carbon mitigation, environmental damage and social welfare across three policy regimes. Fixed baseline parameter values are calibrated as: $a = 100$, $c = 50$, $G = 20$, $k = 10$, $e_o = 10, t = 3, \phi = 0.5$.

Proposition 8. Cross-scenario equilibrium comparisons regarding carbon reduction intensity and supply chain profitability: (1) If $\beta > \frac{12ak-12ck+\sqrt{(12ak-12ck)^2-4(-4a\phi+4c\phi)(-16ak\phi+16ck\phi)}}{8(a\phi-c\phi)}$, $e^{S*} > e^{N*}$, $e^{C*} > e^{S*}$; otherwise, $e^{S*} < e^{N*}$,$e^{C*} > e^{S*}$; (2) If $\beta < \frac{2at-2ct+\sqrt{(-2at+2ct)^2-4(-2a+2c+mt)(8ak-8ck-4kmt-at^2+ct^2)}}{2(-2a+2c+mt)}$, $\pi_R^{C*} < \pi_R^{N*}$, $\beta > -\frac{-3k+\sqrt{k}\sqrt{9k-16\phi^2}}{2\phi}$, $\pi_R^{S*} > \pi_R^{N*}$; (3) If $\beta < \frac{-3a^2k+6ack-3c^2k+(a-c)^2\sqrt{k}\sqrt{9k-16\phi^2}}{2(-a^2\phi+2ac\phi-c^2\phi)}$, $\pi_M^{S*} < \pi_M^{N*}$; $\pi_M^{C*} > \pi_M^{N*}$, if $\beta > -t + \frac{\sqrt{((a-c)^2k-Gt)(-2ckmt+(a-c)^2k(-1+8k)+2akmt-8Gkt-km^2t^2)}}{\sqrt{2}((a-c)^2k-Gt)}$.

Proposition 8 explores the profits of stakeholders and the level of carbon emission reduction by manufacturers under different government policies. Proposition 8(1) indicates that when consumers have a higher preference for low carbon, the level of carbon reduction under the manufacturer subsidy policy is superior to the situation without government policy. Furthermore, this paper found that the level of carbon reduction under the carbon emission trading policy is superior to that under the manufacturer subsidy scenario. When consumers' low-carbon preferences are below the threshold, the carbon reduction level under the laissez-faire policy is higher than that under the manufacturer subsidy policy. Furthermore, this study found that under the cap-and-trade policy, the level of carbon reduction is consistently superior to other government policies (see Figure 2).

Proposition 8(2) indicates that consumers' low-carbon preferences play an important role in affecting retailers' profits. Specifically, when consumers' low-carbon preferences are above (below) the threshold, retailers' profits under the carbon emission trading policy are higher (lower) than those under the anarchy policy scenario. Moreover, Proposition 8(2) also indicates that when consumers' low-carbon preferences are above (below) the threshold, retailers' profits under the manufacturer subsidy policy are higher (lower) than under the anarchy policy (see Figure 3). Similar to the conclusion of Proposition 8(2), Proposition 8(3) indicates that when consumers' low-carbon preferences are above (below) the threshold, manufacturers' profits under carbon emission trading policies and manufacturer subsidy policies are superior to those under the anarchy subsidy policy (see Figure 4).

All three curves show monotonically rising carbon abatement intensity as consumer green preference strengthens. The carbon trading curve permanently sits above the subsidy and laissez-faire lines, proving market-based emission trading delivers the strongest decarbonization incentives regardless of β. Fiscal subsidies only outperform unregulated markets when public green demand crosses the calculated threshold; for low β, manufacturers cut fewer emissions under subsidies than with zero state intervention. This confirms consumer eco-awareness acts as a critical moderator of subsidy policy efficacy, requiring governments to tailor subsidy intensity to local green consumption trends.

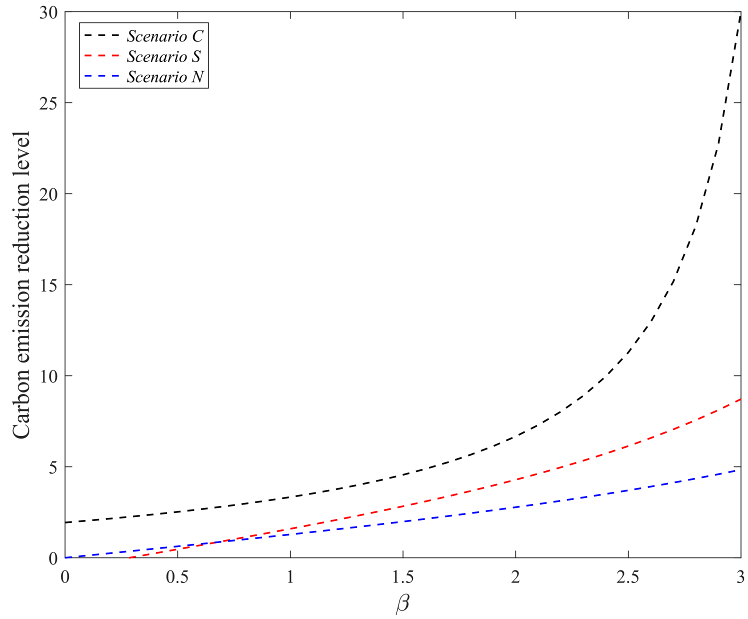

Figure 2. Carbon abatement levels under different government policies

Figure 3 illustrates that retailer profits under the cap-and-trade policy become optimal as β increases. However, for low β, this policy underperforms, as weak demand and higher wholesale prices (driven by the carbon price) suppress retail profitability. In contrast, the subsidy policy yields superior retailer profits for most of the β range, as it encourages production without imposing additional cost burdens on the retailer.

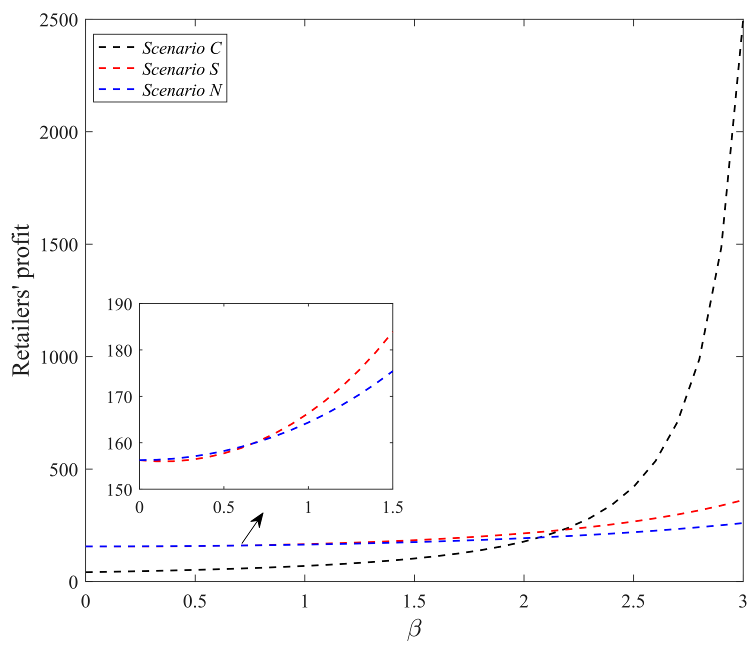

Figure 3. Retailers' profits under different government policies

Figure 4 illustrates a similar trend for manufacturer profits. The cap-and-trade policy leads to optimal profits only at high β levels, as the carbon price imposes a significant cost. However, the subsidy policy consistently yields the highest manufacturer profits across a wide range of β, highlighting its direct financial benefit to the manufacturer. This suggests that while the cap-and-trade is better for the environment, the subsidy is more favorable for the manufacturer's bottom line.

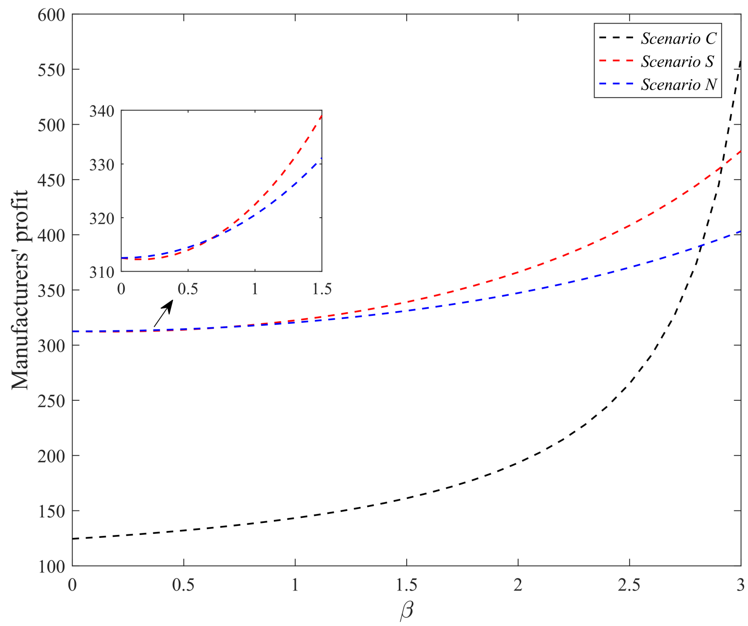

Figure 4. Manufacturers' profits under different government policies

Figure 5 reveals that consumer surplus is maximized under the cap-and-trade policy when β is high. This is because robust consumer demand and effective abatement under this policy create greater perceived value and utility. At low β, however, the no-policy or subsidy scenarios may be preferable, as the higher costs imposed by the cap-and-trade system suppress consumption.

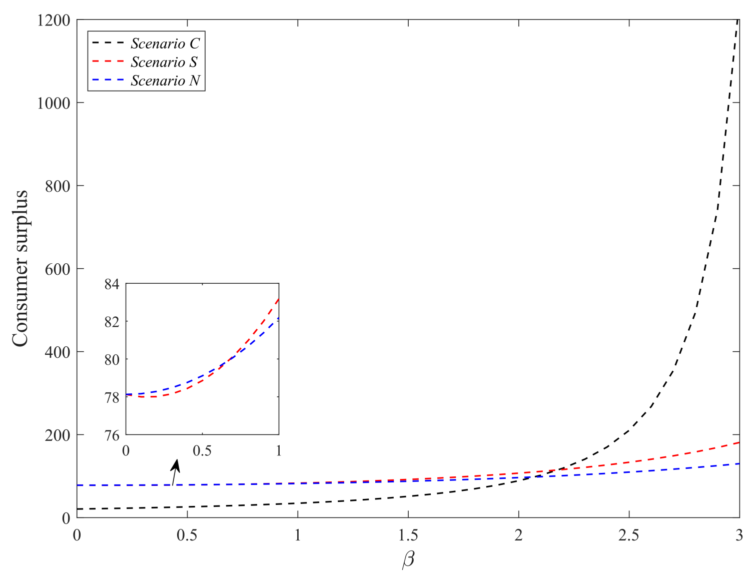

Figure 5. Consumer surplus under different government policies

Proposition 9. Comparing the environmental impacts under different government policies, the authors have the following equilibrium results: If $\beta > \frac{3k}{2\phi} - \frac{1}{2}\sqrt{\frac{9k^2-16k\phi^2}{\phi^2}}$, $EI^{S*} > EI^{N*}$, $EI^{C*} > EI^{S*}$; otherwise,

$EI^{S*} < EI^{N*}$, $EI^{C*} > EI^{S*}$.

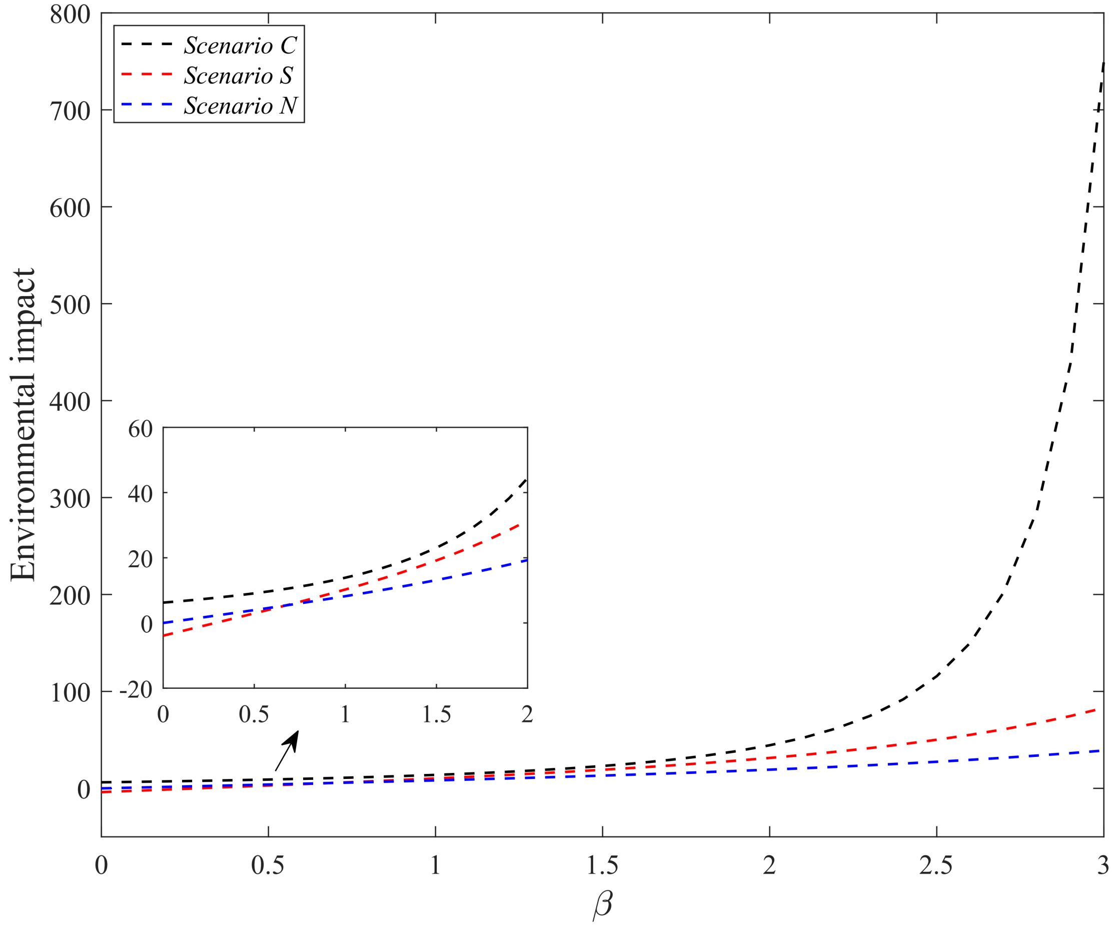

Figure 6. Environmental impact under different government policies

Ecological harm increases with consumer green preference across all policy regimes, driven by expanded overall manufacturing output despite rising unit emission cuts (see Figure 6) . The carbon trading curve always lies below the subsidy and laissez-faire lines, demonstrating market-based trading minimizes aggregate environmental damage. Fiscal subsidies only outperform unregulated markets when β exceeds the threshold derived in Proposition 9; with weak consumer eco-demand, subsidy regimes generate worse ecological outcomes than zero regulation, as expanded production volumes offset limited emission-cutting progress. Laissez-faire markets consistently produce the most severe environmental degradation at all preference levels.

In Figure 7, this paper further explores the joint effects of clean technology cost and consumer preference on environmental impact. Consistent with intuition, environmental impact decreases with higher clean technology investment costs (as manufacturers adopt more expensive, effective abatement) and lower consumer preferences (which dampens overall production). A key insight from Figure 7(a)-(c) is that the relative performance of policies changes with k. At low k, the subsidy scheme can be quite effective. However, as k increases, the cap-and-trade policy becomes increasingly more favorable for minimizing environmental harm.

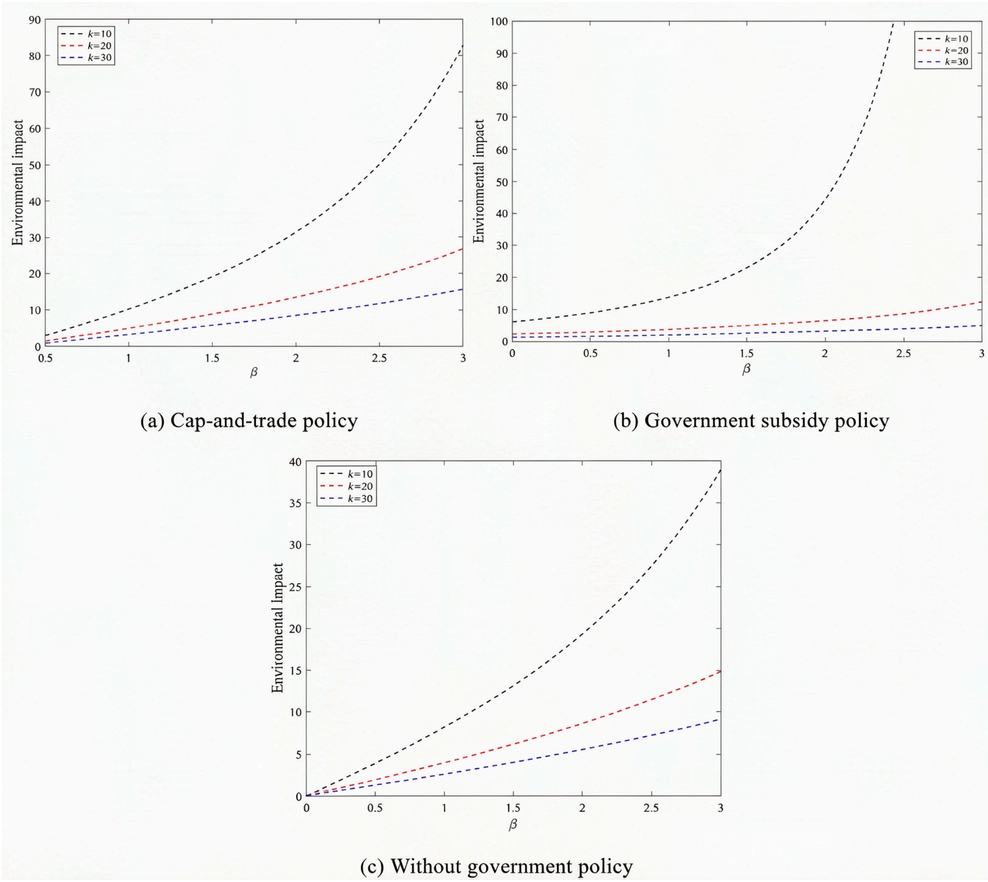

Figure 7. Environmental impacts under different clean technology investment costs and government policies

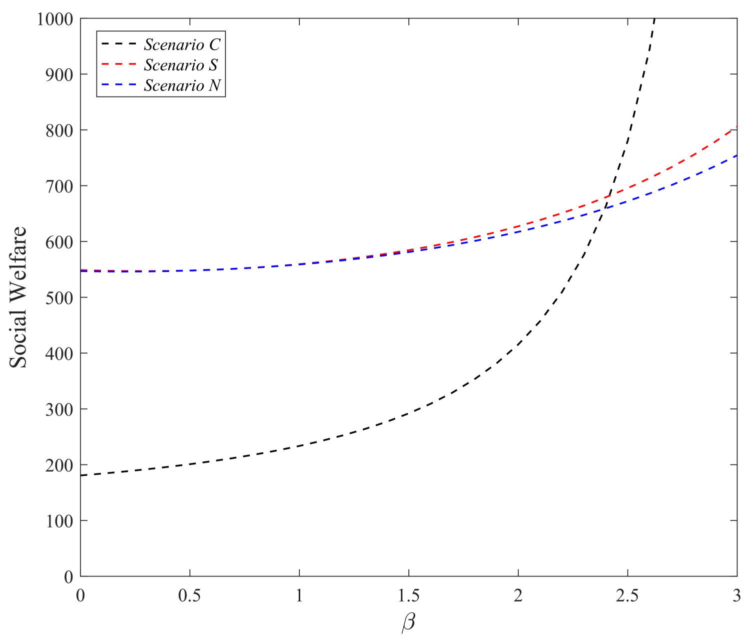

Figure 8. Social welfare under different government policies

Figure 8 examines social welfare. While the cap-and-trade policy yields the highest social welfare at high β levels, the subsidy policy emerges as the superior choice for low to moderate levels. This suggests that, from a holistic societal perspective, the direct financial support to manufacturers via subsidies can be more effective at improving overall welfare, particularly when consumer demand for green products is not yet strong enough to drive abatement through market mechanisms alone.

6. Conclusion

The first key finding of this study is that the carbon cap-and-trade policy consistently delivers the highest level of carbon abatement and the lowest environmental impact, irrespective of consumer preferences. This underscores its effectiveness as a primary regulatory tool for driving decarbonization. However, this study also finds that manufacturer subsidies do not always yield positive abatement outcomes, particularly when consumer preference for green products is low. This suggests that subsidies should be carefully targeted and potentially complemented by demand-side policies.

Second, the authors find that while the cap-and-trade policy is most effective for the environment, the manufacturer subsidy policy is more beneficial for the profitability of both supply chain members. When consumer preference exceeds a certain threshold, profits are maximized under the cap-and-trade regime; below this threshold, subsidies are more effective at boosting profitability. This creates a potential tension between environmental goals and business interests, which policymakers must navigate.

Finally, the analysis of social welfare reveals a nuanced picture. While the cap-and-trade policy is superior at high levels of consumer preference, the subsidy policy yields higher overall social welfare at low to moderate levels. This suggests that in markets where green consumerism is nascent, a direct subsidy policy may be the most effective approach to improve both business performance and societal well-being.

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