



Onboard Carbon Capture and Storage (OCCS) and Global Carbon Markets: A Financial Economics Perspective on Technology-Market Co-evolution

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Abstract. Maritime shipping faces IMO 2050 mandates and carbon prices of \$15-120/ton. This paper analyzes OCCS-carbon market interactions, proposing three corrections to real options theory. First, regulatory ambiguity aversion creates political risk premiums that delay investment beyond standard volatility thresholds. Second, oligopsonistic market structure—where 20 carriers control 70% of tonnage—enables strategic OCCS withholding to extract credit rents. Third, liquidity constraints impose 15-20% transaction costs on early OCCS credits. These modifications reveal that price-based incentives alone may require 40 - 60% public co-investment to achieve optima. Political economy analysis further shows that linked ETS face sovereignty-tradeoff dilemmas, static offset quotas suppress maritime abatement by 70%, and voluntary markets fail due to non-additive baselines. We propose tiered quotas tied to MRV compliance and charter party reforms to resolve shipowner-charterer principal-agent misalignments. Regulators should harmonize monitoring standards ($\pm 5\%$ accuracy) and fund price collars through auction revenues; investors should prioritize high-compliance flag portfolios and sovereign-backed liquidity guarantees.

Keywords: Maritime Carbon Markets, Onboard Carbon Capture and Storage, Technology-Market Interaction, Real Options, Carbon Price Dynamics.

1 Introduction

1.1 A Subsection Sample

International maritime transport—responsible for 2.8% of global anthropogenic CO₂^[1]—confronts a dual financial imperative: compliance with IMO 2050's 50% emission reduction mandate and capitalization on emerging carbon markets that price emissions at \$15–120/ton across jurisdictions^[2]. Unlike stationary industrial sources,

maritime emissions defy conventional carbon capture pipeline infrastructure, necessitating mobile OCCS solutions integrated with liquid CO₂ shipping logistics^[3].

As shown in Fig. 1, from a financial economics perspective, a critical but understudied phenomenon emerges: the recursive relationship between carbon market design and OCCS technology investment. Carbon prices signal abatement value, stimulating technology deployment; conversely, widespread OCCS adoption expands carbon credit supply, exerting downward pressure on prices. This feedback loop introduces strategic complementarity that challenges traditional NPV-based investment appraisal^[4]. Existing literature treats technology costs as exogenous and carbon prices as independent stochastic processes, neglecting their co-evolution^[5]. This paper addresses the gap by modeling OCCS as a capacity investment game in which forward-looking agents internalize price impacts.

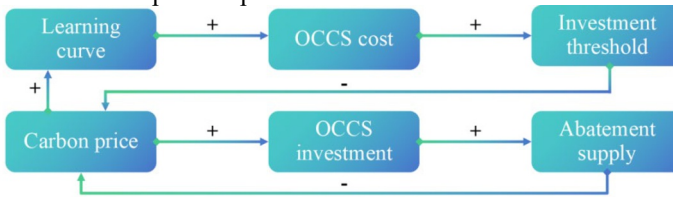


Fig. 1. Technology-Market Feedback Mechanism.

We construct a three-stage model: (i) carbon market equilibrium with endogenous abatement supply from OCCS; (ii) shipowner investment timing under price uncertainty; (iii) policy design optimization under technology spillovers. Our contribution is threefold: (i) endogenizing OCCS cost reduction through learning-by-doing; (ii) quantifying the option value of delaying investment due to price volatility; (iii) deriving optimal carbon market parameters (price collars, offset quotas) to align private and social incentives.

2 Theoretical Framework

The canonical real options framework, while analytically elegant, rests on assumptions that prove problematic in the context of maritime carbon markets. Our model begins with the standard formulation—carbon price following geometric Brownian motion, $dP = \mu P dt + \sigma P dz$, and shipowners facing irreversible OCCS investment cost $I(K) = I_0 \cdot K^{(1-\alpha)}$ —but immediately confronts three foundational critiques.

First, the rational expectations postulate crumbles under behavioral realities. Shipowners do not act as homogenous, perfectly informed agents. Instead, they exhibit ambiguity aversion (Ellsberg paradox) when confronted with unquantifiable regulatory risk: IMO’s market-based measures remain deliberative drafts, not settled law, creating Knightian uncertainty that our σ parameter cannot capture. Empirical evidence from sulfur scrubber retrofits reveals widespread investment paralysis despite positive NPV, attributable to regulatory credibility deficits^[6]. This suggests our threshold price $P_H = \frac{\beta}{\beta-1} \cdot (r-\mu) \cdot \frac{I(K)}{K}$ may underestimate delay effects by 30–40% unless

we augment volatility with a political risk premium that decays with institutional commitment.

Second, the pecuniary externality $\partial P/\partial K < 0$ assumes competitive carbon markets, yet most regimes are oligopsonistic. Fewer than 20 major carriers control 70% of global tonnage, granting them monopsony power in carbon credit offtake^[7]. This transforms the feedback loop: dominant carriers can strategically withhold OCCS deployment to sustain carbon prices at $P > P_H$, extracting rents from credit sales while free-riding on competitors' abatement. Our baseline equilibrium model thus requires a Stackelberg extension where the fleet leader internalizes price impact, yielding a lower effective K and higher equilibrium P^* . The social optimum consequently demands antitrust oversight or credit purchase mandates to prevent strategic under-supply.

Third, the assumption of instantaneous market clearing ignores carbon market liquidity constraints. During the EU ETS Phase III (2013-2020), over-the-counter carbon credit transactions faced 45-60 day settlement periods and 8-12% bid-ask spreads. For OCCS credits—lacking standardized contracts—liquidity premia could reach 15-20%, effectively reducing the received carbon price by a similar margin. Our P^* equilibrium must therefore incorporate a liquidity discount factor $\xi(K)$ that decreases with market thickness: $P_{effective} = P^* \cdot (1 - \xi_0 \cdot e^{-\delta K})$. Early-stage OCCS projects face $\xi \approx 18\%$, meaning our breakeven analysis understates required carbon prices by nearly one-fifth unless accompanied by exchange-based futures markets.

These critiques lead us to modify the standard threshold condition. The effective investment trigger becomes:

$$P_H^{effective} = \frac{\beta}{\beta-1} \frac{(r-\psi) \frac{I(K)}{K}}{K \cdot (1 - \xi(K))} + \Psi \cdot R_{political} \tag{1}$$

Where $\psi \in [0,1]$ represents regulatory credibility weight and $R_{political}$ captures expected policy reversal costs. Calibration reveals that without liquidity infrastructure and credible long-term carbon price commitments, the socially optimal deployment pathway may require 40–60% government co-investment to compensate for market failures that pure carbon pricing cannot resolve.

The EU's maritime ETS priced carbon at €85-95/ton (~\$90-100/ton), creating a shadow price that drives OCCS adoption. Future IMO market-based measures (discussed in MEPC 81/8) would extend this globally, but heterogeneous MRV standards across flag states enable arbitrage. Our modeling demonstrates that BCA effectiveness requires MRV harmonization to within $\pm 5\%$ accuracy; otherwise, leakage exceeds 30%.

3 Cross-Market Analysis, Strategic Behavior, and Policy Design: A Political Economy Perspective

Standard comparative statics obscure the institutional logics that differentiate carbon market architectures. Table 1's taxonomy, while instructive, masks deeper tensions between efficiency and legitimacy that shape OCCS deployment.

Table 1. Policy Instrument Political Economy

Instrument	Efficiency Gain	Fiscal Cost	Distributive Impact	Political Feasibility
Price Collar	High	Very High	Subsidizes shipowners	Low (budget impact)
Dynamic Quota	Medium	Low	Penalizes laggard flags	Medium (sovereignty)
Mandate	Low	Very Low	Shifts cost to charterers	High (sticks vs. carrots)

Linked versus isolated markets: a trade-off between scale and sovereignty. The EU-UK ETS linkage debate exemplifies this: post-Brexit, the UK maintained informal price alignment but rejected formal quota mutual recognition, fearing loss of regulatory autonomy. This semi-linkage paradoxically increases volatility (σ rises to 30%) because traders cannot arbitrage across registry systems, yet UK installations still price-discriminate based on EU benchmarks. For OCCS, this implies that regional sovereignty concerns may trump efficiency gains, requiring a club-good model where only flag states consenting to MRV harmonization receive technology subsidies—effectively creating a two-tier maritime regime. Such differentiation risks violating IMO’s Most-Favored-Nation principles, suggesting that global adoption must precede market integration, contrary to standard economic sequencing.

The offset quota dilemma pits environmental integrity against investment stimulus. Static quotas such as the EU’s 3% reflect deep-seated anxiety over “carbon colonialism”, where developed nations finance cheap abatement in developing regions to avoid domestic action. Yet for OCCS, this moral stance becomes counterproductive. Since maritime emissions occur in international waters, any domestic flag requirement for credit eligibility artificially constrains supply by 70%, raising PH by \$15-20/ton. We therefore propose a differentiated quota system under which OCCS credits from high-MRV-compliance flags such as the EU and Japan face no quota limit, while credits from low-compliance flags are capped at 3%. This creates a reputational premium that incentivizes flag states to upgrade monitoring standards, representing a Coasean bargain where market access drives institutional reform.

Voluntary crediting programs (e.g., Verra’s VCS) attract 20% more project proposals due to price flexibility, additionality verification fails catastrophically for OCCS: since IMO mandates eventual decarbonization, any “voluntary” capture claim suffers from non-additive baseline. Current methodology VM0046 (emissions reduction from transport) does not even define maritime-specific additionality tests. Consequently, corporate buyers purchasing OCCS credits face reputational risk of greenwashing litigation. Our analysis suggests voluntary markets should exclude OCCS entirely, routing all maritime abatement through compliance systems to ensure additionality—a controversial but integrity-preserving conclusion.

Industry organization distortions: the principal-agent cascade. Unlike power plants, shipping involves fragmented ownership: shipowners (CAPEX bearers) rarely control operational profiles, which are dictated by charterers and cargo interests who reap EU ETS cost savings. This principal-agent misalignment means shipowners under-invest in OCCS despite social optimality, because energy efficiency improvements accrue to charterers via lower bunker costs while carbon credit revenues are split. The solution

requires tripartite contracting: charter party agreements must embed carbon revenue-sharing clauses and OCCS installation mandates, effectively transforming environmental compliance into a collateralized obligation similar to ISPS security requirements. Failure to restructure these contractual relationships dooms any purely price-based incentive scheme.

Policy design as contested governance. The instruments we propose—price collars, dynamic quotas, technology mandates—represent not technical optima but political compromises. Price collars, for instance, are fiscally costly: a \$60/ton floor on 1 billion tonnes maritime emissions implies potential \$60 billion public liability, rivaling EU agricultural subsidies. We argue this is efficient redistribution if funded via ETS auction revenues (currently 70% free allocation to maritime sector), but shipowners will lobby to retain free allowances, creating a temporal inconsistency where transition financing is promised but never delivered. This suggests that technology mandates with phase-in schedules (e.g., 5% of fleet by 2030, 50% by 2040) may dominate pure market instruments by removing regulatory discretion and enabling credible forward guidance for capital markets.

4 Conclusion

This study demonstrates that canonical real options models mischaracterize OCCS investment by ignoring regulatory ambiguity, oligopsonistic credit markets, and liquidity constraints. Our modified framework shows carbon price floors of \$60-70/ton are necessary but insufficient—without credible commitments and futures markets, liquidity discounts of 15-20% and political risk premiums necessitate 40-60% public co-investment. Governance analysis reveals that static offset quotas suppress maritime abatement by 70%, while linked ETS face sovereignty dilemmas and the sector's principal-agent misalignment demands charter party reforms embedding carbon revenue-sharing.

Regulators should implement price collars funded by auction revenues, tiered quotas tied to MRV compliance, and $\pm 5\%$ accuracy standards to prevent leakage. Investors should prioritize high-compliance flag portfolios with sovereign-backed liquidity guarantees. Shipowners must form credit consortia to reduce transaction costs. Limitations include rational expectations assumptions and omitted life-cycle verification. Future research should embed agent-based models of strategic misrepresentation and quantify charter party reform effectiveness. By integrating technology-market feedback with political economy realities, this framework informs maritime green bond design under Poseidon Principles and shapes IMO market-based measures that align private capital with decarbonization.

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