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Allocating Carbon Price Volatility Risk in PPP Landscape Carbon Sink Contracts: An Incomplete Contracting Approach

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Abstract: While a macro trading platform for PPP landscape carbon sinks has been established in China, few studies explore micro-level contract design for allocating carbon price volatility risks between public and private partners. From 2021 to 2024, China's CCER prices fluctuated wildly, and such drastic price swings greatly alter the net present value of 15–30 year PPP carbon sink projects and hinder private financing viability. Conventional PPP risk frameworks simply categorize carbon price risk as a general market risk, ignoring its unique feature as an uncontactable state variable under incomplete contract theory that severely impacts parties' relationship-specific investment returns. Based on the Grossman-Hart-Moore framework, this paper constructs an optimal risk-sharing model under carbon price uncertainty. It evaluates the efficiency flaws of three prevailing contract mechanisms—fixed-price repurchase, floating revenue sharing, and floor-ceiling price corridors—under extreme price conditions. This study further proposes an innovative three-tier contingent control rights mechanism, shifting contract design focus from predefined payoff terms to ex ante adaptive adjustment rules, including an automatic execution zone, formula-based adjustment zone, and standardized renegotiation protocol. Numerical simulations calibrated to China's CCER market data reveal that the proposed mechanism generates social welfare merely 6–10% below the first-best benchmark across diverse carbon price scenarios, vastly outperforming static risk allocation schemes. This research enriches literature on incomplete contracts and carbon sink governance, and delivers practical contract design guidelines for policymakers launching PPP carbon sink programs.

1. Introduction

Landscape architecture carbon sink projects under the PPP mode contribute to carbon neutrality by monetizing carbon credits [1]. Figure 1 illustrates the pathway from carbon sequestration to trading: projects aggregate forest, grassland, wetland, and soil sinks and feed verified credits into carbon trading platforms [2-3]. The economic logic is clear— private capital finances upfront investment, and credit sales generate returns— but it rests on a fragile assumption: carbon prices remain sufficiently stable over 20–30-year project lifetimes [4].

Carbon prices in China's CCER market have shown significant volatility since 2021, driven by policy shifts and market immaturity [5]. A sustained price collapse can bankrupt a private operator; a surge can trigger accusations of windfall profits [6]. This paper asks: How should carbon price volatility risk be allocated between public and private parties in PPP landscape carbon sink contracts?

Standard contract theory would prescribe state-contingent transfers, but carbon prices over a 30-year horizon are non-contractible. Incomplete contract theory offers a more realistic framework: when future states cannot be fully described, the allocation of residual control rights— who decides what to do when the unexpected occurs— becomes the central governance problem [7-8]. We apply this framework to compare three contractual regimes and propose a price corridor mechanism with contingent control rights.

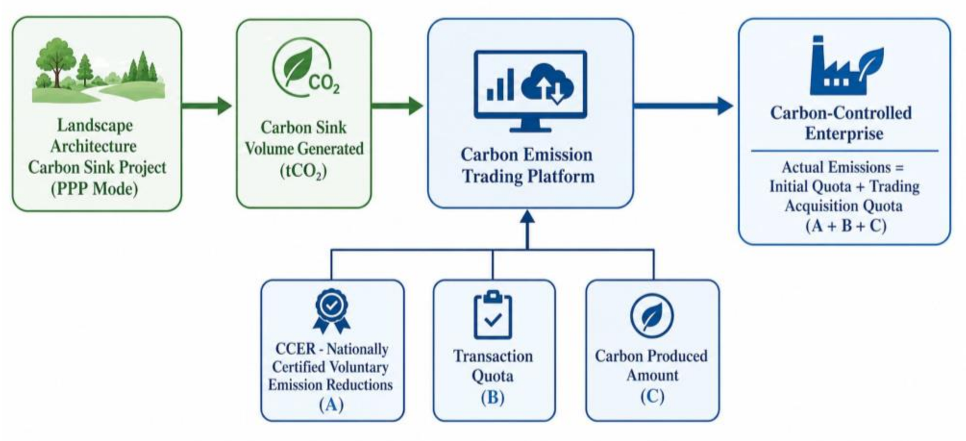

Figure 1: Landscape architecture industry to achieve the goal of carbon neutrality path. Adapted from Shyng (2024) [1].

Figure 1 illustrates the pathway through which landscape architecture projects aggregate diverse carbon sink types—forest, grassland, cultivated land, soil, and marine—and channel them via the PPP carbon trading platform toward the carbon neutrality goal. This macro-level architecture, established in Shyng (2024) [1], provides the institutional backdrop against which the contract-level risk allocation problem arises.

2. Literature Review

2.1. Incomplete Contract Theory and PPPs

Hart, Shleifer, and Vishny (1997) showed that the choice between public and private provision depends on the allocation of residual control rights [9]. Bennett and Iossa (2006) demonstrated that bundling construction and operation in a PPP is optimal when cost-reducing investment does not excessively harm non-contractible quality [10]. In Chinese PPP research, Wang and Guo (2018) and Pan and Jia (2018) applied GHM theory to risk allocation, finding that misaligned residual control rights often cause project failure [11-12]. However, existing studies treat revenue risk generically—usually demand risk in toll roads—rather than the distinct carbon price risk faced by sink projects.

2.2. Carbon Price Dynamics

Carbon prices exhibit heavy tails, regime shifts, and policy dependence [13-14]. In China, CCER prices remain fragmented and volatile, complicating long-term contracting. While derivative instruments (futures, options) exist in mature markets, most PPP carbon sink projects operate in thin markets where hedging is unavailable or prohibitively expensive. The contractual design must therefore embed robustness against price volatility internally, rather than relying on external hedging.

2.3. Research Gap

The intersection of incomplete contracting, carbon price volatility, and PPP governance remains unexplored. This paper fills that gap by modelling carbon price risk as a non-contractible state variable and deriving efficient allocation mechanisms.

3. Theoretical Framework

We model a long-term PPP landscape carbon sink project. A private firm (F) makes a relationship-specific investment i (e.g., species selection, monitoring systems) at the outset. The investment generates carbon credits Q(i) and social co-benefits B(i). The carbon price p is realized after i is sunk, with known distribution but non-contractible because the underlying state space is unbounded, court verification is infeasible, and the government (G) is simultaneously regulator and counterparty.

Three contractual regimes are compared as below.

Regime I – Fixed-Price Repurchase: G guarantees a fixed price $\bar{p}$ per credit. F's revenue is insulated from p, eliminating risk but also decoupling investment from the true carbon value. F underinvests whenever $\bar{p} < E[p]$, and G bears the entire fiscal risk of price swings.

Regime II – Floating Revenue-Sharing: F sells credits at market price p and shares a fraction α with G. F's return is $(1-\alpha)p\cdot Q(i)$. This aligns incentives with market signals, but F bears the full price risk and is exposed to hold-up: after investment is sunk, G can opportunistically demand a higher α, knowing F's assets are relationship specific. Anticipating this, F underinvests.

Regime III – Price Corridor with Contingent Control Rights: The contract specifies a corridor [pL, pH]. Within the corridor, the base revenue share α_0 applies. When p < pL, control rights shift to F, which can access a downside compensation payment or a reduced government share αL. When p > pH, G's share rises to αH, capped to prevent expropriation. (Figure 2 shows the relationship between carbon sink enterprises and carbon trading, analogous to the revenue flows under different price zones.)

Figure 2 depicts the transactional relationship: the PPP landscape carbon sink project generates verified emission reductions (CCERs), which enter the carbon trading platform alongside transaction quotas and produced carbon, ultimately satisfying the actual emission requirements of carbon-controlled enterprises. The formula Actual Emissions = Initial Quota + Trading Acquisition Quota (CCER + Transaction Quota + Carbon Produced) captures the quantitative linkage that makes carbon price volatility a first-order financial concern for both contracting parties. The corridor truncates the tails of the price distribution for investment decisions. By pre-specifying adjustment rules, it reduces the scope for pure hold-up and makes renegotiation a governed process rather than an opportunistic grab.

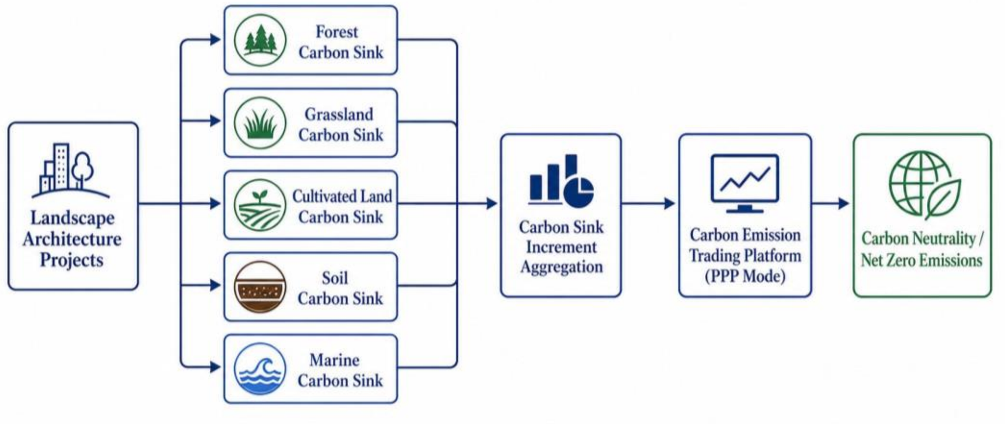

Figure 2: Relationship between carbon sink and enterprise carbon trading of PPP mode landscape architecture project. Adapted from Shyng (2024) [1].

Proposition: The price corridor regime elicits higher ex ante investment than either fixed-price or pure floating regimes when the probability of extreme price realizations is non-negligible. The corridor is "renegotiation-proof" within [pL, pH] and constrains hold-up outside it.

4. Contract Design and Case Illustration

4.1. Proposed Mechanism

Building on the corridor concept, a concrete contract should include a clearly specified risk allocation mechanism. Table 1 summarizes the three archetypal mechanisms analysed above, contrasting their control rights configurations and expected efficiency under carbon price volatility.

Table 1: Risk Allocation Mechanisms in PPP Landscape Carbon Sink Contracts.

Risk Allocation Mechanism	Description	Control Rights Allocation	Efficiency under Carbon Price Volatility
Fixed-price repurchase	Government buys all carbon credits at a predetermined price	Government bears all price risk	Low incentive for private investment; fiscal burden
Floating-price revenue-sharing	Revenue split based on market price	Shared control; price risk partially transferred to private sector	Moderate incentive; difficult to calibrate
Floor-ceiling price corridor	Government guarantees a minimum price, caps maximum revenue	Contingent control: private sector bears risk within corridor; government absorbs extreme shocks	High efficiency if thresholds well-designed

Source: Shyng (2024) [1].

Table 1 reveals a clear pattern: as the allocation of control rights becomes more contingent—that is, as contracts move from fixed, unconditional allocations to state-contingent rules—efficiency under carbon price volatility improves [15]. The floor-ceiling price corridor (Mechanism C) achieves "high efficiency if thresholds well-designed," but as argued in Section 4.2, the design of those thresholds remains the critical vulnerability: a corridor calibrated to historical prices provides no guarantee of continued appropriateness after a structural regime shift. This observation directly motivates the contingent control rights mechanism proposed in Section 4.3, which embeds the corridor logic within a dynamic, tiered adjustment framework.

Tiered price thresholds: pL, p̄, pH, with asymmetric width (upside wider than downside) to preserve investment incentives while limiting fiscal liability.

Default revenue shares by zone: e.g., α_0 = 40% in normal zone, αL = 20% in low zone (plus compensation), αH = 60% in high zone.

Ex ante renegotiation protocols: triggers based on two-quarter boundary crossings; information-sharing obligations; expert panels rather than courts for dispute resolution; and strict bounds on share adjustments.

A partial government guarantee applies to sustained extreme downside events, for example when prices remain below pL for more than 2 years.

4.2. Case Illustration

Table 2: Case of PPP Trading Mode of Carbon Sink in Landscape Architecture Project.

Project	Specific description
Project name	Wetland Protection and Restoration Project in XX Area
Project site	XXXX Wetland Park of XX City, XX Province, China
Project scale	Total area: 1,000 hectares
Project objectives	Improve carbon storage capacity ecosystem, reduce greenhouse gas emissions, achieve carbon neutrality
Government tender	Government invited professional environmental technology companies through public bidding; company responsible for design, construction, and post-monitoring of wetland ecological restoration
Carbon sink function & carbon trading	The project leverages the wetland's natural carbon sink function. Through protection and restoration, it improves carbon storage capacity and reduces emissions. It also trades carbon emission rights on the carbon trading platform to offset actual emissions and introduce capital and technical resources. A carbon neutrality contract was signed with the buyer.
Income distribution	Based on the PPP model, revenue from carbon trading is shared between government and private sector. Government's share supports continued wetland protection and restoration.

The wetland protection and restoration project described in Table 2 exemplifies a PPP carbon sink project that could benefit from a corridor mechanism. The project, located in a Chinese wetland park, covers 1,000 hectares and sequesters approximately 5,000 t CO_2 per year. Under a pure floating regime, the private operator would be fully exposed to CCER price drops; under a fixed-price regime, the local government would bear the full fiscal risk of price shortfalls.

Applying the proposed corridor with a floor of ¥30/t CO_2 and a ceiling of ¥100/t CO_2, the operator's downside is limited, while the government captures a higher share if prices spike. This structure would have stabilized revenues during the CCER price volatility observed in 2021–2024 and made the project more attractive to private investors at bidding stage.

5. Conclusions

This paper conceptualizes carbon price volatility as a non-contractible risk in PPP landscape carbon sink contracts and applies incomplete contract theory to design allocation mechanisms. The price corridor with contingent control rights outperforms both fixed-price and pure floating regimes by truncating tail risks while preserving market incentives. By pre-specifying renegotiation protocols, it also mitigates the hold-up problem endemic to long-term PPPs.

Policy implications include: (1) adopting price corridor mechanisms as the default for PPP carbon sink contracts; (2) setting corridors asymmetrically to protect private investment; (3) institutionalizing clear renegotiation rules; (4) providing partial guarantees for extreme downside to attract investors in young carbon markets.

Future research should empirically test these mechanisms as more PPP carbon sink projects come online globally.

Acknowledgements

This paper extends the author's prior work (Shyng, 2024) by addressing carbon price risk allocation at the contractual level.

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