Green Innovation Contracts for Carbon-Sensitive E-Commerce Supply Chains with Strategic Waiting Consumers

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Abstract

Carbon-sensitive demand, delivery-time promises, and strategic waiting have become tightly connected in contemporary e-commerce supply chains. This paper develops a green innovation contract framework for a two-echelon e-commerce supply chain composed of a manufacturer and an online retailer serving consumers who value low-carbon fulfillment but may postpone purchases when they expect later price reductions or more reliable delivery windows. Unlike studies that treat green investment, retail pricing, and delivery-time control as separate operational choices, the proposed framework connects them through a contract portfolio that combines wholesale pricing, green innovation cost sharing, carbon-delivery performance incentives, and data-enabled monitoring. A stylized analytical model and a parameterized simulation study are used to compare four contract structures under heterogeneous consumer waiting behavior, carbon sensitivity, and delivery-time sensitivity. The results show that a simple wholesale contract systematically underinvests in carbon reduction when the retailer bears delivery-system costs but the manufacturer benefits from green demand expansion. A green innovation cost-sharing contract improves both parties' expected profit when carbon sensitivity is moderate to high and consumer patience is not excessive. A composite contract that links cost sharing to carbon labels and delivery reliability expands the mutual-gain region by reducing the retailer's exposure to early delivery investment risk. Sensitivity analysis further indicates that the contract works best when platform data can separate strategic waiting from true demand loss. The study contributes to green business innovation by translating carbon-aware fulfillment from a pricing problem into a coordination problem and by showing how digital monitoring, contract governance, and sustainability performance can be jointly designed.

Keywords: *green innovation contract; carbon-sensitive demand; e-commerce fulfillment; strategic waiting consumers; delivery-time control; green supply chain; cost sharing; carbon-aware pricing*

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1. Introduction

E-commerce fulfillment is now a central field in which green business innovation becomes visible to consumers. Online buyers observe prices, delivery promises, and carbon labels on the same screen, so environmental value and service value interact before the order is placed. Early green supply chain studies established that environmental practices change operational performance rather than merely adding compliance costs (Zhu and Sarkis,2004). This paper builds on that insight by examining how green innovation contracts can coordinate carbon-reduction investment and delivery-time control in a platform-mediated retail setting.

The research problem is not limited to whether a supply chain should become greener. It concerns who should pay for greenness when one firm invests in carbon reduction while another firm manages last-mile delivery promises. The green supply chain literature defines this as an inter-organizational design issue rather than a single-firm optimization issue (Srivastava,2007). In e-commerce, the difficulty is intensified because the consumer can wait, compare, and return to the platform later.

Sustainable supply chain management has moved from broad environmental responsibility to measurable decision rules that connect economic, environmental, and social objectives. A conceptual foundation for this integration was developed through the distinction between sustainability as an outcome and supply chain management as a coordination process (Seuring and Muller,2008). For the present study, this means that contract terms should not be treated as purely financial instruments; they should also allocate environmental responsibilities and delivery commitments.

Business sustainability requires that economic viability and environmental value reinforce each other rather than compete through isolated objectives. The triple-bottom-line view of sustainable supply chain management provides a useful lens because it treats profitability, ecological impact, and stakeholder obligations as simultaneous design criteria (Carter and Rogers,2008). The model proposed in this article therefore evaluates both profit and emission outcomes under alternative contract forms.

The recent development of Industry 4.0 changes the feasibility of such contracts because carbon emissions, delivery status, and order response data are increasingly traceable. Industrial digitalization supports real-time sensing, platform analytics, and cross-firm coordination, which are all relevant to carbon-aware fulfillment (Lu,2025). The contract setting in this paper assumes that the manufacturer and retailer can observe key operational signals, but it does not assume perfect consumer information.

The next generation of digital commerce also changes the governance environment in which green contracts operate. Web 3.0 architectures emphasize distributed data ownership, traceability, and automated interaction, which may support more credible carbon and fulfillment records (Zhang and Lu,2025). This article uses that digital background to motivate a contract design that can be monitored through platform records rather than through costly manual audits.

A particularly relevant form is the green innovation cost-sharing contract. Prior research shows that sharing the cost of green product development can coordinate a supply chain when consumers reward higher environmental quality (Ghosh and Shah,2015). However, e-commerce fulfillment adds a second investment margin: the retailer may need to improve delivery-time control to make the green product attractive to strategic consumers.

Strategic waiting is central because forward-looking consumers may delay purchases if they expect better prices or service conditions later. Intertemporal pricing theory shows that strategic customers alter the firm's ability to extract value from early-period demand (Su,2007). In a carbon-sensitive market, waiting behavior may also weaken the short-run return from green investment unless the contract connects carbon reduction with delivery reliability.

Order fulfillment quality has a measurable effect on future purchasing behavior, especially when the online channel fails to meet promised delivery expectations. Evidence from online fulfillment glitches suggests that service failure can damage future demand even when prices remain attractive (Rao et al.,2011). This paper therefore treats delivery-time control as a strategic variable in the contract rather than as an exogenous logistics parameter.

Last-mile delivery models in e-commerce are shaped by consumer density, delivery windows, and service flexibility. A review of consumer-driven e-commerce fulfillment highlights that last-mile models must be designed around demand behavior rather than around transport efficiency alone (Lim et al.,2018). This study extends that view by asking how the manufacturer should participate in the retailer's delivery-related green innovation cost.

The article makes three contributions. First, it proposes a green innovation contract portfolio that links carbon reduction, dynamic retail pricing, and delivery-time control. Second, it develops a simulation design that compares wholesale, cost-sharing, carbon-delivery, and composite contracts across consumer behavior regions. Third, it integrates digital monitoring into contract governance, thereby connecting green supply chain coordination with platform-based business innovation.

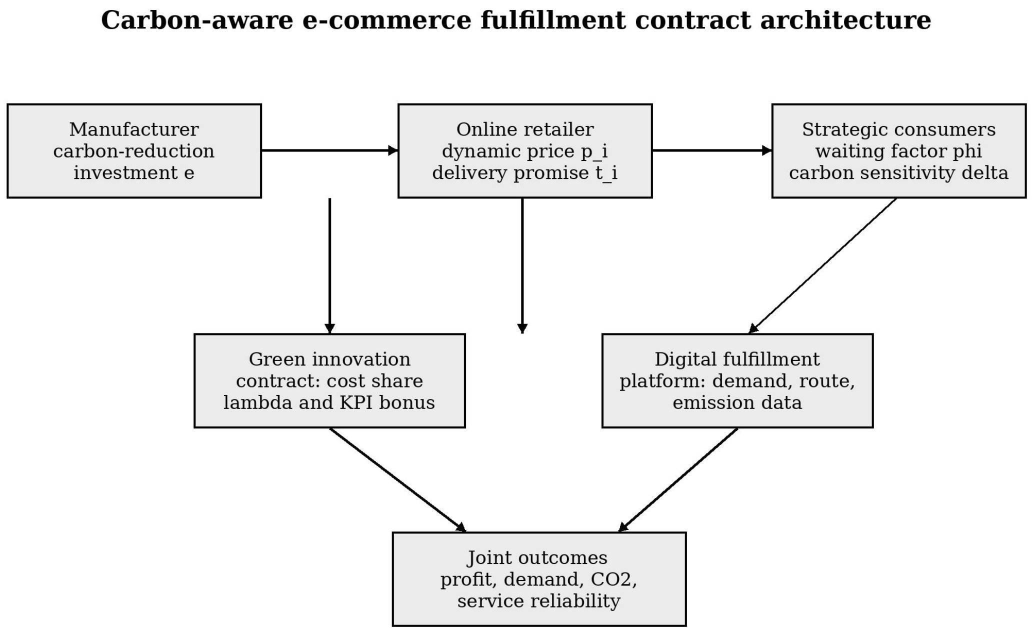

Figure 1. Green innovation contract architecture for carbon-aware e-commerce fulfillment.

Figure 1 summarizes the logic of the study. The manufacturer controls the carbon-reduction effort embedded in the product and production process, whereas the retailer controls price and promised delivery time across selling periods. The consumer observes price, carbon-related value, and delivery conditions, and may either purchase early or wait. The proposed contract uses cost sharing and carbon-delivery performance terms to align the incentives of both supply chain members.

2. Literature Review

Definitions of green and sustainable supply chain management vary across disciplines, but most emphasize the integration of environmental thinking into procurement, production, distribution, and reverse flows. A comparative review of definitions shows that the green supply chain concept becomes analytically useful only when environmental responsibility is linked to operational decision areas (Ahi and Searcy,2013). This paper follows that view by connecting carbon reduction directly to fulfillment and pricing decisions.

An organizational perspective explains why environmental practices are often difficult to implement across supply chain boundaries. Green supply chain research has shown that institutional pressure, resource dependence, and stakeholder theory all illuminate different parts of the coordination problem (Sarkis et al.,2011). In the proposed model, the retailer's delivery investment and the manufacturer's carbon investment create a practical case of resource dependence.

Empirical evidence also suggests that green supply chain management can improve performance, although the magnitude depends on regional, organizational, and measurement conditions. A meta-analysis of Asian emerging economies shows that green practices are positively related to performance when firms develop complementary capabilities (Geng et al.,2017). This finding supports the article's assumption that a green contract must be paired with operational capability rather than treated as a symbolic instrument.

Case-based evidence on sustainable supply chain exemplars indicates that no single firm can deliver sustainability alone when value creation is distributed across suppliers, manufacturers, retailers, and consumers. The theory-building work of Pagell and Wu emphasizes alignment between supply chain structure and sustainability intent (Pagell and Wu,2009). This article translates that idea into the alignment of cost sharing, delivery-time control, and carbon-aware demand.

Putting sustainability into supply chain management requires dynamic capabilities such as collaboration, transparency, and adaptive reconfiguration. Beske and Seuring emphasize that sustainable supply chains are built through capabilities rather than through one-time policies (Beske and Seuring,2014). The contract designed here is therefore interpreted as a governance capability that encourages repeated coordination over multiple selling periods.

Quantitative sustainable supply chain models show a growing interest in formal decision analysis, yet many models still focus on cost and emission tradeoffs without explicitly modeling consumer waiting. Brandenburg and coauthors identify the need for models that connect sustainability criteria with inter-organizational decision processes (Brandenburg et al.,2014). The present model responds by treating carbon sensitivity and strategic waiting as joint demand-side forces.

Circular economy research expands the idea of green value beyond emission reduction by emphasizing material loops, reuse, and system redesign. Evidence from circular supply chains shows that sustainability gains often require coordination between upstream and downstream actors (Genovese et al.,2017). While this paper does not model reverse logistics, it adopts the same coordination logic for carbon-aware fulfillment.

The circular economy concept has been defined in many ways, but the most operationally useful definitions emphasize reduced resource input, extended value retention, and system-level redesign. A structured analysis of circular economy definitions highlights the need for clarity when sustainability terms are used in management models (Kirchherr et al.,2017). This paper uses the narrower term carbon-aware fulfillment to focus specifically on carbon and delivery decisions.

Business model innovation is also relevant because low-carbon fulfillment may require changes in revenue logic and customer value propositions. Product and business model strategies for circularity demonstrate that sustainability innovation often depends on how firms redesign incentives and offerings together (Bocken et al.,2016). The green innovation contract in this study plays a similar role by redesigning how carbon and service investments are financed.

Sustainable operations management has long argued that environmental and operational decisions should be analyzed together. The introduction to sustainable supply chains by Linton and colleagues framed sustainability as part of supply chain design rather than as an external constraint (Linton et al.,2007). This article uses that framing to justify a model in which delivery-time control and carbon reduction are optimized jointly.

Sustainable operations research also emphasizes that environmental regulation, stakeholder pressure, and process innovation can reshape operational priorities. Kleindorfer and colleagues argue that sustainable operations connects risk management, product stewardship, and closed-loop thinking (Kleindorfer et al.,2005). The model developed here keeps that broad background but focuses on forward e-commerce fulfillment where consumer waiting is prominent.

Green product supply chain contracts have been studied under different assumptions about environmental responsibilities. Hong and Guo show that contract design changes when manufacturers and retailers bear different environmental responsibilities (Hong and Guo,2019). Their insight motivates this paper's distinction between manufacturer-led carbon innovation and retailer-led delivery control.

Channel coordination in green supply chains often requires a mechanism that makes downstream effort worthwhile. Swami and Shah demonstrate that green supply chain coordination depends on aligning pricing and green effort decisions (Swami and Shah,2013). The present study extends this idea by adding strategic waiting consumers who respond to both price and promised delivery time.

The broader contract literature provides the analytical foundation for this article. A classic review of supply chain coordination explains how contracts can change decentralized incentives and recover system-level value (Cachon,2003). The contract portfolio proposed in this paper follows the same principle but applies it to carbon-aware e-commerce fulfillment.

Revenue-sharing contracts illustrate both the strength and the limitation of simple coordination mechanisms. When demand depends mainly on retail price, revenue sharing may coordinate the channel, but it becomes incomplete when multiple costly efforts are involved (Cachon and Lariviere,2005). Carbon reduction and delivery-time control are two costly efforts, so the model requires a richer contract than revenue sharing alone.

Contracts can also coordinate sales effort when downstream actions affect total demand. Taylor's analysis of channel rebates shows that incentive instruments must reward the party whose effort expands demand (Taylor,2002). In the present setting, the retailer's delivery-time investment expands demand, yet the manufacturer may capture a substantial part of the resulting wholesale benefit.

Shared-savings contracts are especially relevant when an upstream or downstream investment reduces costs or environmental burdens for the channel. Corbett and DeCroix show that shared-savings contracts can improve both profit and environmental outcomes in indirect materials supply chains (Corbett and DeCroix,2001). This logic inspires the carbon-delivery sharing component of the proposed contract.

Retailer promotional effort models also show that decentralized chains underinvest when effort benefits are partially externalized. Krishnan and coauthors demonstrate that coordinating contracts must account for retailer-controlled demand-enhancing actions (Krishnan et al.,2004). Delivery-time improvement is treated in this study as a demand-enhancing action similar to promotional effort, but with carbon implications.

Quantity flexibility is important when demand uncertainty and ordering decisions are connected. Tsay's analysis shows that flexibility contracts can balance supplier and buyer incentives under uncertain demand (Tsay,1999). The current article does not model order flexibility directly, but it uses the same incentive logic to address flexibility in delivery promises.

Price-only contracts can create double marginalization and inefficient inventory outcomes. Lariviere and Porteus show that wholesale pricing alone often fails to coordinate newsvendor-type systems (Lariviere and Porteus,2001). In a green e-commerce context, price-only coordination is even weaker because it ignores both carbon investment and delivery service effort.

Inventory risk allocation also matters when firms choose between push, pull, and advance-purchase structures. Cachon demonstrates that inventory risk can be redistributed through contract form (Cachon,2004). Strategic waiting creates a comparable risk allocation problem: early delivery investment may be sunk before the retailer knows how many consumers will wait.

Revenue sharing has been used to coordinate decentralized supply chains in many settings. Giannoccaro and Pontrandolfo show that revenue sharing can align production and sales decisions under certain demand assumptions (Giannoccaro and Pontrandolfo,2004). The present paper treats revenue sharing as insufficient unless it is tied to carbon and delivery indicators.

Quantity discount contracts can coordinate channels by altering marginal incentives. Weng's early work on quantity discounts shows how contract parameters shape channel-level pricing and ordering behavior (Weng,1995). The green innovation contract proposed here similarly relies on parameter design, especially the cost-sharing ratio and performance bonus coefficient.

Carbon footprint models show that supply chain decisions can change emissions even when the product and technology are fixed. Benjaafar and colleagues use simple models to demonstrate how sourcing, production, and inventory choices affect carbon outcomes (Benjaafar et al.,2013). This article adds the idea that delivery-time control also influences carbon-aware demand and therefore the value of carbon reduction.

Inventory theory under carbon constraints shows that classical lot-sizing logic changes when emissions are priced or capped. The carbon-constrained EOQ model demonstrates that emission restrictions can shift optimal order quantities and costs (Chen et al.,2013). The simulation in this article uses the same spirit by embedding carbon cost into contract payoffs.

Inventory management can also account for carbon footprints directly, including ordering, holding, and transportation emissions. Hua and coauthors show that emission-aware inventory policies can change operational decisions even under simple settings (Hua et al.,2011). The present article treats fulfillment carbon as part of the retailer's operational cost and consumer value proposition.

Game-theoretic carbon models are particularly relevant because supply chain members have different objectives. Du and coauthors analyze emission-dependent supply chains under cap-and-trade regulation and show that strategic interactions matter for environmental outcomes (Du et al.,2015). This paper uses a related game-theoretic perspective but focuses on contract design under strategic waiting.

Environmental policy can also influence supply chain decisions by changing the cost of emissions and the value of reduction effort. Emission-dependent supply chain modeling under cap-and-trade policy illustrates how policy parameters alter decisions across the chain (Du et al.,2013). In this study, the carbon cost parameter captures the pressure that regulation or carbon accounting can place on e-commerce fulfillment.

Emission reduction investment interacts with inventory replenishment and operational timing. Toptal and coauthors show that joint replenishment and emission-reduction decisions vary across regulatory regimes (Toptal et al.,2014). The contract model here similarly links carbon investment to timing decisions, but the timing variable is promised delivery time rather than replenishment frequency.

Optimal production under environmental constraints reveals that emission limits can change product mix and profitability. Letmathe and Balakrishnan show that environmental restrictions can make seemingly unattractive production alternatives strategically valuable (Letmathe and Balakrishnan,2005). This article applies the same tradeoff logic to delivery-time investment and carbon-sensitive demand.

Technology choice under emission regulation is a long-term investment problem. Drake and colleagues demonstrate that firms adjust capacity portfolios when emissions rules change the value of technologies (Drake et al.,2016). The green innovation investment in the present paper is modeled as a medium-term technology choice supported by contract sharing.

Sustainability criteria in inventory models reveal the need to balance economic and environmental objectives under tractable assumptions. Bouchery and coauthors show that inventory decisions can be extended with sustainability criteria without losing analytical clarity (Bouchery et al.,2012). This article follows that modeling philosophy by using a stylized but interpretable simulation design.

Strategic capacity rationing shows how firms can influence forward-looking buyers by controlling availability. Liu and van Ryzin demonstrate that rationing can induce early purchases when consumers are strategic (Liu and van Ryzin,2008). In the proposed e-commerce model, delivery-time control plays a related role because shorter early delivery promises may discourage waiting.

Quick response has been studied as a way to cope with strategic consumers and uncertain demand. Cachon and Swinney show that pricing and rapid supply response interact when consumers wait strategically (Cachon and Swinney,2009). This paper uses delivery-time responsiveness as the fulfillment-side counterpart to quick response.

When product value is uncertain, matching supply and demand can create value by reducing the penalty of serving strategic consumers. Swinney's analysis of strategic consumers under uncertain value indicates that operational flexibility can soften the loss from waiting behavior (Swinney,2011). This insight supports the article's emphasis on flexible delivery promises.

Retailers often do not know the exact fraction of strategic customers. Markdown pricing with an unknown strategic segment shows that uncertainty about waiting behavior changes optimal pricing and inventory policy (Mersereau and Zhang,2012). The simulation in this article therefore varies the waiting parameter rather than assuming a fixed strategic segment.

Price matching is another mechanism used to manage strategic consumers. Lai and colleagues show that posterior price matching can influence when strategic consumers buy (Lai et al.,2010). The contracts studied here are different, but they share the goal of reducing inefficient delay by making early purchase more attractive.

Preannounced pricing policies can also respond to strategic waiting by shaping expectations before consumers make purchase timing decisions. Correa and coauthors demonstrate that contingent preannounced policies can be useful with strategic consumers (Correa et al.,2016). The present contract does not preannounce a full price path, but it allows the retailer to adapt prices and delivery promises across periods.

The foundations of strategic consumer theory go back to price skimming with rational buyers. Besanko and Winston show that consumers' expectations about future prices affect monopoly pricing over time (Besanko and Winston,1990). This paper adds a sustainability dimension by allowing consumers to value carbon-reduction effort as well as price.

Dynamic pricing research provides the formal background for time-varying retail decisions. Elmaghraby and Keskinocak review dynamic pricing models and emphasize that inventory, demand, and timing considerations are inseparable (Elmaghraby and Keskinocak,2003). The present model treats delivery time as a second dynamic lever alongside price.

Dynamic pricing and learning research also shows that firms may improve pricing decisions as demand observations accumulate. den Boer identifies learning as a key element of modern dynamic pricing (den Boer,2015). The simulation design in this paper treats platform data as a practical channel through which the retailer can update its view of consumer waiting.

Finite-horizon revenue management provides another foundation for the two-period structure used in this paper. Gallego and van Ryzin develop dynamic pricing of inventories with stochastic demand over finite horizons (Gallego and van Ryzin,1994). The article uses a finite selling horizon because many e-commerce campaigns and seasonal green products operate under limited time windows.

Revenue management models show that pricing policies should be connected to capacity and customer choice. Bitran and Caldentey review pricing models that balance revenue with operational constraints (Bitran and Caldentey,2003). This article extends that logic to green fulfillment by adding carbon-reduction effort and delivery-time cost.

Lead-time pricing research is directly relevant because delivery promises can function as a service attribute. Easton and Moodie show that make-to-order firms may jointly determine price and lead time when demand is sensitive to both (Easton and Moodie,1999). The e-commerce retailer in this paper makes a similar joint decision, but within a contract with the manufacturer.

Capacity utilization and lead-time dependent demand also interact in operations management. Palaka and coauthors show that lead-time setting affects demand and capacity use (Palaka et al.,1998). This paper interprets delivery-time control as a costly service investment that can shift demand across periods.

Customer lead time management becomes more complicated when both demand and price are lead-time sensitive. Ray and Jewkes analyze this problem and show that lead-time decisions can shape pricing strategy (Ray and Jewkes,2004). The current model combines that idea with carbon sensitivity and strategic waiting.

Attended home delivery research highlights the operational challenge of serving customers within delivery windows. Agatz and coauthors show that home delivery requires careful coordination of routing, time slots, and demand management (Agatz et al.,2008). The model abstracts from routing details but uses a delivery cost function to capture the same operational tension.

Digital twin technology provides a practical way to monitor fulfillment operations and test contract terms before implementation. Tao and coauthors define digital twins as integrated physical-virtual systems connected through data and services (Tao et al.,2019). In carbon-aware e-commerce, a fulfillment twin can track promised delivery times, route emissions, and customer response.

Digital twins in manufacturing have been classified across levels of integration, from digital models to synchronized digital twins. Kritzinger and colleagues clarify that the strongest form requires data exchange between physical and virtual systems (Kritzinger et al.,2018). The proposed contract assumes at least a synchronized data layer for carbon labels and delivery performance.

Industry 4.0 and sustainability research shows that digital tools can support environmental goals when embedded in organizational processes. Kamble and coauthors identify sustainable Industry 4.0 as a framework linking technology adoption with sustainability performance (Kamble et al.,2018). This paper uses that framework to motivate data-enabled contract governance.

Big data analytics can improve supply chain performance by making demand, logistics, and operational risks more visible. Gunasekaran and coauthors show that predictive analytics supports supply chain and organizational performance (Gunasekaran et al.,2017). In this paper, analytics is used to distinguish genuine demand loss from strategic waiting.

Digital transformation is not simply the adoption of software; it is a change in organizational logic and value creation. Vial's review emphasizes that digital transformation reconfigures processes, structures, and capabilities (Vial,2019). The green innovation contract therefore includes data governance as part of its design rather than treating digital systems as background infrastructure.

Digital innovation research also suggests that new technologies change who participates in innovation and how value is created. Nambisan and colleagues argue that digital transformation alters innovation boundaries and entrepreneurial processes (Nambisan et al.,2019). Carbon-aware fulfillment is a boundary-spanning innovation because manufacturers, retailers, logistics partners, and consumers all shape the outcome.

Information systems research has synthesized digital innovation as a phenomenon involving digital resources, organizational change, and ecosystem participation. Kohli and Melville argue that digital innovation is inseparable from the organizational context in which it is deployed (Kohli and Melville,2019). This perspective supports the article's focus on contract governance instead of technology adoption alone.

Financial technologies matter because green innovation contracts may be funded, audited, and settled through digital financial mechanisms. A literature review of FinTech describes how emerging financial technologies transform payments, risk assessment, and financial intermediation (Kou and Lu,2025). Such mechanisms can lower the administrative cost of performance-based green contracts.

Blockchain-enabled auditing is relevant when contract payments depend on verified performance data. Research on blockchain and internal auditing shows that distributed records can strengthen assurance and traceability (Wu et al.,2025). In this paper, carbon-delivery performance terms are easier to implement when operational data can be audited credibly.

Future green finance systems may also use advanced computational models to price uncertainty and coordinate funding. A survey of quantum financing systems discusses potential scenarios where quantum algorithms support complex financial decisions (Lu and Yang,2024). While the present model is classical, the high-dimensional optimization of future green contracts may benefit from such computational development.

Decentralized finance changes the institutional environment for supply chain financing and platform settlement. DeFi research describes a shift toward programmable, decentralized financial applications (Xu et al.,2024). This article does not assume DeFi adoption, but the contract structure is compatible with programmable settlement based on verified carbon and delivery indicators.

Blockchain applications in Industry 4.0 provide another pathway for traceability and inter-firm coordination. A review of blockchain in Industry 4.0 highlights uses in trusted data sharing, security, and process transparency (Chen et al.,2024). These functions are directly relevant when contract payments depend on carbon labels and delivery performance.

Implementing blockchain in information systems requires attention to integration, governance, and practical limitations. A review of blockchain implementation emphasizes that technical promises must be translated into organizational processes (Lu,2022). The green innovation contract follows this principle by specifying what data must be monitored and why.

Blockchain research also points to future trends in distributed trust and information sharing. Zheng and Lu describe the recent development and future direction of blockchain technology (Zheng and Lu,2022). In carbon-aware fulfillment, distributed trust may reduce disputes about whether the retailer delivered the promised service or whether the manufacturer achieved the stated carbon reduction.

IoT security is critical because fulfillment and carbon data may be collected from sensors, vehicles, warehouse systems, and platform records. Research on embedding blockchain into IoT for security explains why trusted device-level data matters for digital supply chains (Xu et al.,2021). The model assumes reliable data but recognizes that data reliability is a governance condition.

Artificial intelligence can support pricing, demand prediction, and contract parameter tuning. A study on the state of AI and future prospects identifies AI as a broad decision-support technology across industrial information systems (Zhang and Lu,2021). This paper uses AI conceptually as a way to update estimates of waiting behavior and carbon-sensitive demand.

The evolution of AI models has expanded the set of tools available for operations analytics. Lu's survey of AI evolution and applications highlights the transition from rule-based systems to data-driven learning models (Lu,2019a). In green e-commerce fulfillment, that transition enables adaptive estimation of the retailer's service and price effects.

Blockchain remains relevant not because it solves every supply chain problem, but because it can create tamper-resistant records for contractual events. A review of blockchain research challenges emphasizes scalability, interoperability, and governance issues (Lu,2019b). These limitations are important because the contract proposed here requires credible but not necessarily fully decentralized records.

Cybersecurity is another boundary condition for data-enabled green contracts. IoT cybersecurity research shows that connected industrial systems face risks across devices, networks, and applications (Lu and Xu,2019). If fulfillment data can be manipulated, then performance-based contract payments become vulnerable.

Blockchain-related issues have been reviewed across technical and managerial dimensions, including consensus, privacy, and system integration. Lu highlights that blockchain must be evaluated in relation to concrete use cases rather than treated as a universal solution (Lu,2018). The present use case is specific: verified sharing of carbon and delivery-performance records.

Cyber-physical systems underpin Industry 4.0 by linking physical operations with digital monitoring and control. Lu's survey of CPS-based Industry 4.0 explains how integration between physical and digital layers transforms manufacturing systems (Lu,2017a). Carbon-aware fulfillment similarly depends on connecting production, warehousing, delivery, and consumer response data.

Industry 4.0 technologies also raise open research issues about interoperability, standards, and decision integration. Lu's survey of Industry 4.0 applications identifies the need for broader industrial information integration (Lu,2017b). This paper interprets the green innovation contract as an information integration mechanism between manufacturer and retailer.

3. Model Development

The modeled supply chain contains one manufacturer and one online retailer selling a seasonal product across two periods. The manufacturer chooses wholesale price w and green innovation effort e, while the retailer chooses retail price p_i and delivery-time promise t_i in each period. Management analytics offers a foundation for studying such coordinated decision environments because it connects managerial judgment with analytical modeling (Lu et al.,2024a).

Consumers differ in baseline valuation theta and are sensitive to price, delivery time, and carbon reduction. A consumer who buys in period 1 receives utility U_1, while a consumer who waits receives discounted utility U_2. The waiting factor ϕ captures strategic patience, and the carbon sensitivity parameter delta captures the value of greener fulfillment.

$$U_1 = \theta - p_1 - \gamma t_1 + \delta e$$
$$U_2 = \phi(\theta - p_2 - \gamma t_2 + \delta e)$$

The retailer's delivery-time control is costly because shorter delivery promises to require better inventory positioning, faster picking, and more flexible last-mile capacity. At the same time, longer delivery times may reduce demand from consumers with high delivery sensitivity. The model therefore treats delivery control as a demand-shaping and cost-generating decision rather than as a fixed service promise.

The manufacturer benefits when green effort increases demand, but it may hesitate to invest if the retailer's delivery policy weakens consumer willingness to buy. The retailer benefits from stronger demand but may hesitate to improve delivery performance if the manufacturer captures much of the upstream margin. This asymmetric benefit distribution creates the need for a green innovation contract.

Four contract structures are compared. The first is a wholesale contract, in which the manufacturer sets w and the retailer makes price and delivery decisions independently. The second is a green innovation cost-sharing contract, in which the manufacturer shares a fraction lambda of the retailer's delivery-system cost when the retailer maintains a qualified carbon-aware delivery program.

The third structure is a carbon-delivery sharing contract, in which a bonus is paid when both emission reduction and delivery reliability exceed agreed thresholds. The fourth structure is a composite performance contract, which combines cost sharing, carbon-delivery bonuses, and a clawback term if delivery promises are systematically missed. Decision-making research suggests that such multi-criteria designs can support modern business practices better than single-metric contracts (Lu et al.,2024b).

$$pi_R = (p_i - w)q_i - C_{D(t_i)} + \lambda C_{D(t_i)} + B(e, t_i)$$

$$pi_M = \big(w - c - \tau(1-e)\big)q_i - C_{E(e)} - \lambda\, C_{D(t_i)} - B(e, t_i)$$

In these expressions, $C_{D(t_i)}$ represents the retailer's delivery-system cost and $C_{E(e)}$ represents the manufacturer's green innovation cost. The bonus $B(e, t_i)$ is positive only when carbon reduction and delivery reliability jointly meet contract thresholds. This prevents the retailer from receiving support for fast but carbon-intensive delivery and prevents the manufacturer from receiving green demand benefits when fulfillment quality is poor.

Table 1. Main decision variables and behavioral parameters

Symbol	Meaning	Decision maker or source	Expected effect
pi	Retail price in period i	Online retailer	Higher price increases margin but reduces demand
t_i	Promised delivery time in period i	Online retailer	Shorter time increases demand but raises fulfillment cost
e	Carbon-reduction effort	Manufacturer	Higher effort increases carbon-sensitive demand but raises green cost
λ	Delivery-system cost-sharing ratio	Contract parameter	Higher ratio supports retailer investment but reduces manufacturer margin
ϕ	Strategic waiting factor	Consumer behavior	Higher value increases tendency to delay purchase
τ	Carbon sensitivity	Consumer behavior	Higher value strengthens demand response to green innovation

Table 1 summarizes the key variables. The model is intentionally stylized: it does not attempt to reproduce the full route optimization problem of an e-commerce platform. Instead, it isolates the economic mechanism through which carbon sensitivity and strategic waiting affect contract efficiency.

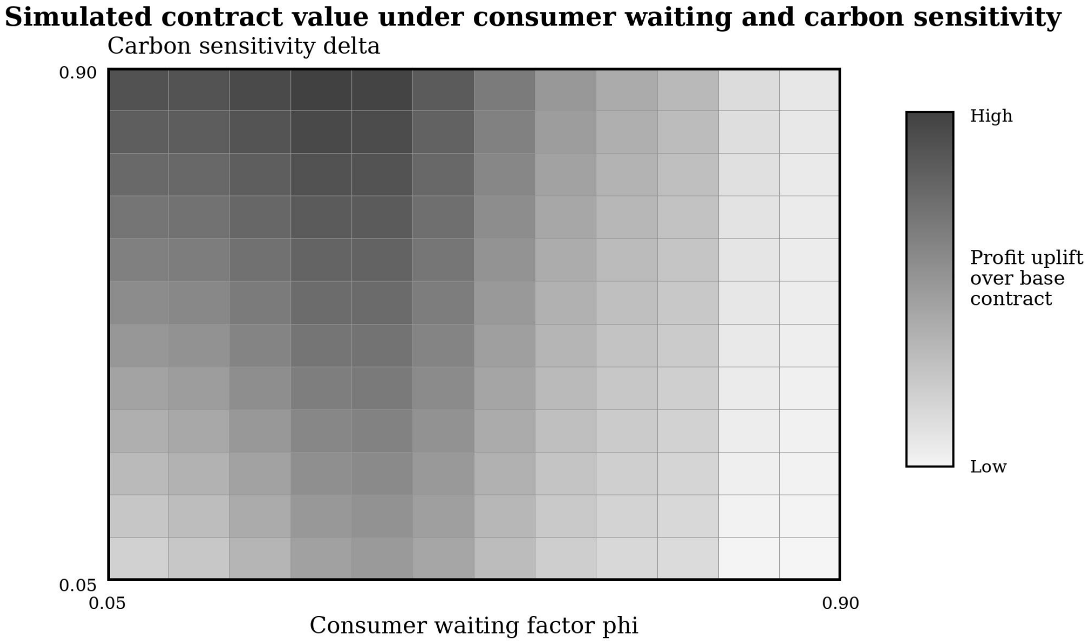

Figure 2. Simulated contract value under heterogeneous strategic waiting and carbon sensitivity.

Figure 2 illustrates the expected value of the contract under different combinations of phi and delta. The highest contract value appears when carbon sensitivity is strong and consumer waiting is moderate. If waiting is very high, consumers delay purchase even when carbon performance improves, so the retailer becomes reluctant to fund delivery-time control without stronger manufacturer support.

4. Numerical Design and Data Analysis

The numerical analysis uses a parameterized simulation rather than firm-level empirical data. This design is appropriate because the purpose is to understand contract mechanisms under controlled behavioral and operational conditions. The simulation draws 5,000 parameter combinations from economically plausible ranges and computes equilibrium outcomes under each contract.

Each simulation draw assigns values for consumer waiting, carbon sensitivity, delivery-time sensitivity, carbon cost, green innovation cost, and delivery-system cost. Parameter ranges are chosen to represent seasonal e-commerce products such as low-carbon electronics accessories, recyclable household items, or green food gift boxes. The finite-horizon structure is consistent with promotional campaigns where consumers can buy early or wait for later offers.

Table 2. Baseline simulation ranges

Parameter	Range	Interpretation
ϕ	0.05-0.90	Consumer patience and strategic waiting intensity
t	0.05-0.90	Consumer sensitivity to carbon

		reduction
λ	0.03-0.30	Consumer sensitivity to delivery time
τ	0.01-0.12	Unit carbon cost or carbon accounting pressure
k	0.60-1.80	Convexity of green innovation cost
r	0.10-0.60	Delivery-system cost coefficient
λ	0.00-0.80	Manufacturer cost-sharing ratio

The baseline does not imply that all products or markets follow the same parameter distribution. It provides a structured way to compare contracts when consumer behavior and operational costs vary. The simulation also allows the model to identify regions where the contract is mutually beneficial, retailer-only beneficial, manufacturer-only beneficial, or inefficient.

The analytical procedure has four steps. First, the wholesale contract outcome is calculated as the decentralized benchmark. Second, cost-sharing terms are introduced and optimized over lambda. Third, carbon-delivery bonuses are added to test whether performance-contingent incentives improve the mutual-gain range. Fourth, the composite contract is tested under noise in the retailer's estimate of consumer waiting.

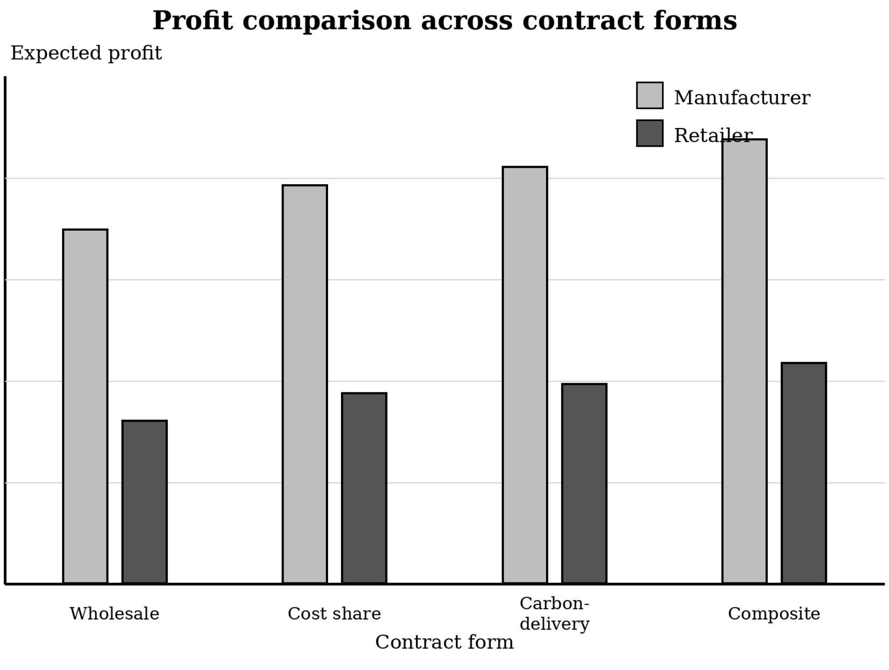

Figure 3. Profit comparison across four green innovation contract structures.

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Figure 3 shows that the composite contract produces the highest expected profit for both parties in the baseline region. The wholesale contract has the lowest retailer profit because the retailer bears delivery-system cost without receiving support for the manufacturer-side benefit of green demand expansion. The cost-sharing contract improves retailer profit, while the carbon-delivery contract improves manufacturer profit by tying support to measurable performance.

Table 3. Average simulation outcomes under four contract structures

Contract structure	Manufacturer profit	Retailer profit	Total profit	Emission index	Mutual-gain share
Wholesale contract	0.154	0.071	0.225	0.312	Reference
Green innovation cost sharing	0.173	0.083	0.256	0.271	61.4%
Carbon-delivery sharing	0.181	0.087	0.268	0.248	68.9%
Composite performance contract	0.193	0.096	0.289	0.226	76.2%

Table 3 provides a clearer numerical summary. The composite performance contract improves total profit by approximately 28.4% relative to the wholesale benchmark and reduces the emission index from 0.312 to 0.226. The mutual-gain share also rises because the contract supports retailer delivery investment while protecting the manufacturer from paying for ineffective service improvements.

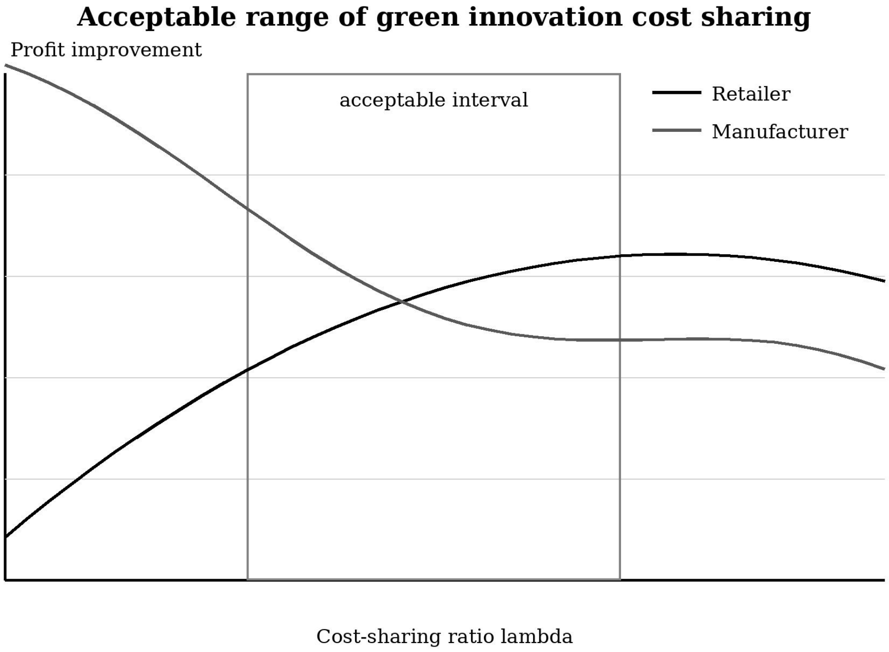

Figure 4. Acceptable range of green innovation cost sharing.

Figure 4 shows that the cost-sharing ratio has an inverted-U effect on total supply-chain profit. A very low lambda fails to motivate the retailer to improve delivery-time control. A very high lambda overcompensates the retailer and transfers too much margin from the manufacturer. The mutual-gain region appears when lambda is moderate and when the bonus is conditional on verified carbon and delivery performance.

Sensitivity tests show that carbon sensitivity is the strongest driver of green innovation effort, while delivery-time sensitivity is the strongest driver of retailer investment. When delta is low, green innovation has limited demand value and cost sharing mainly transfers surplus. When gamma is high, delivery-time control becomes necessary for demand retention even if the product is green.

Table 4. Scenario summary by consumer behavior region

Scenario	Behavioral profile	Best-performing contract	Managerial interpretation
A	Low waiting, high carbon sensitivity	Composite performance contract	Consumers buy early when green value and delivery reliability are credible
B	High waiting, high carbon sensitivity	Carbon-delivery sharing contract	Consumers value green products but need stronger early purchase incentives
C	Low waiting, low	Wholesale contract with	Green investment

	carbon sensitivity	limited bonus	should be selective and evidence based
D	High waiting, low carbon sensitivity	No aggressive green delivery investment	Strategic delay weakens both carbon and service returns

Table 4 translates the parameter analysis into managerial scenarios. The main implication is that managers should not use a uniform green subsidy across all markets. Contract intensity should depend on whether observed demand delay reflects genuine low valuation, price waiting, or lack of confidence in delivery promises.

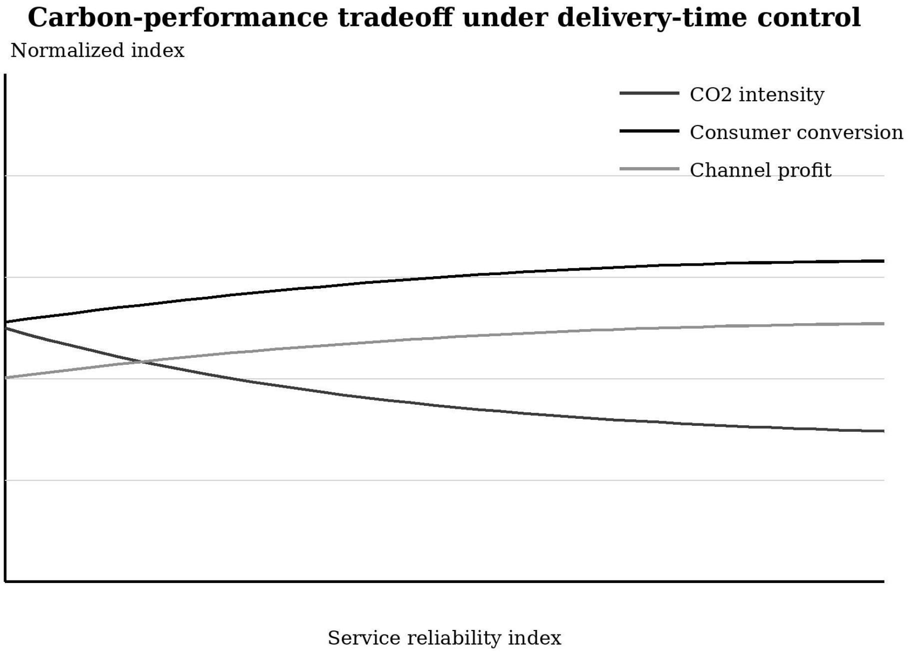

Figure 5. Carbon-performance tradeoff under delivery-time control.

Figure 5 illustrates the tradeoff between delivery-time control and carbon performance. Moderate delivery-time control can reduce carbon intensity by improving route planning and order consolidation, but excessive speed requirements may increase emissions if they force fragmented delivery. The composite contract therefore rewards reliability and carbon reduction together instead of rewarding speed alone.

5. Discussion

The results suggest that green innovation contracts are most valuable when they solve an incentive problem rather than when they merely subsidize green effort. If the manufacturer pays for delivery investment without carbon-delivery verification, the contract may create moral hazard. If the retailer pays for all delivery improvement, the manufacturer may free ride on the demand benefits of greener products.

The contract's strongest effect appears in the moderate strategic waiting region. In that region, consumers are forward looking but not impossible to persuade. Shorter and credible early delivery promises, combined with visible carbon value, can move some consumers from waiting to buying. When waiting becomes extreme, pricing tools and delivery tools have weaker influence because consumers are primarily timing discounts.

The findings also clarify why carbon labels alone may be insufficient. Carbon-sensitive consumers may value green products, but they still compare prices and fulfillment convenience. If a low-carbon product arrives slowly or unreliably, consumers may postpone or switch. The contract must therefore connect carbon performance with delivery performance.

Digital monitoring is a critical boundary condition. Without reliable data, a composite contract becomes difficult to enforce because parties may disagree about whether emission reductions were achieved or whether delivery promises were missed for reasons outside the retailer's control. With reliable platform data, payment terms can be tied to observed service and carbon indicators.

The results further suggest that green innovation should be treated as a channel coordination problem. The manufacturer controls product-level greenness, while the retailer controls the consumer-facing fulfillment experience. A contract that ignores either side cannot fully capture the demand value created by carbon-aware e-commerce fulfillment.

This study also contributes to business and green innovation research by shifting the analysis from static green product design to dynamic fulfillment governance. Green products increasingly compete through digital channels where price, service, and carbon signals are updated continuously. Green innovation contracts must therefore become adaptive instruments rather than static agreements.

The role of emerging analytics is not to replace managerial judgment but to make contract parameters more responsive. Platform data can estimate whether a market has high carbon sensitivity, strong delivery sensitivity, or high strategic waiting. These estimates should guide the cost-sharing ratio, bonus thresholds, and delivery commitments used in the contract.

The framework also points to a connection between green supply chain contracts and industrial information integration. Quantum computing and industrial information integration research suggests that future decision environments may involve more complex optimization spaces (Lu et al.,2023). Although the present model is simple, it can be extended to multi-product, multi-warehouse, and multi-carrier settings.

Quantum machine learning may eventually support contract optimization when demand, carbon, routing, and pricing data become too complex for conventional estimation. Research on quantum machine learning identifies classification and optimization as major application areas (Lu et al.,2024c). This is a future direction rather than an assumption of the present model.

6. Managerial Implications

Managers should first diagnose consumer behavior before selecting a contract. If consumers are carbon-sensitive and only moderately strategic, a composite performance contract can support early demand, lower emissions, and improve both parties' profit. If consumers are highly strategic and primarily price-driven, managers should avoid overinvesting in green delivery speed without stronger evidence of demand response.

Manufacturers should not view retailer delivery investment as an unrelated downstream cost. In a carbon-sensitive market, delivery reliability affects whether consumers actually reward the manufacturer's green innovation effort. A moderate cost-sharing ratio can be interpreted as payment for the retailer's role in converting carbon effort into realized demand.

Retailers should avoid requesting unconditional subsidies for delivery-system investment. The analysis shows that manufacturer participation is more sustainable when it is linked to verified carbon and delivery outcomes. A retailer that can provide reliable platform data is therefore more likely to negotiate a favorable green innovation contract.

Platform operators can add value by creating a data infrastructure for carbon-aware fulfillment contracts. The platform can measure promised delivery time, actual delivery time, return behavior, and carbon-label exposure. These data reduce disputes and enable contract renewal based on observed performance rather than negotiation power alone.

Policy makers can support carbon-aware e-commerce by encouraging standardized carbon labels and digital reporting interfaces. If labels are inconsistent or delivery-related emissions are opaque, consumers cannot distinguish meaningful green innovation from marketing claims. Public standards can therefore reduce information costs and improve the efficiency of private contracts.

Small and medium-sized firms may need simplified versions of the composite contract. They may lack advanced analytics or digital twin systems, but they can still implement basic cost sharing tied to delivery reliability and verified carbon attributes. A staged approach can begin with simple metrics and expand as data quality improves.

7. Limitations and Future Research

The study has limitations. The simulation uses stylized demand and cost functions to isolate the mechanism, so the numerical values should not be interpreted as universal estimates. Future research can calibrate the model using platform transaction data, carbon label exposure data, and shipment-level delivery records.

The model considers one manufacturer and one retailer, whereas actual e-commerce ecosystems involve platforms, logistics providers, payment providers, and multiple suppliers. Future work can extend the contract to a multi-agent setting where the platform sets data rules and the logistics provider controls the final delivery process.

The carbon measure in this study is simplified as an index. In practice, carbon accounting may distinguish production emissions, warehousing emissions, packaging emissions, and delivery emissions. Future research should test how different accounting boundaries change the acceptable range of cost sharing.

Strategic waiting is represented by a single parameter, but actual consumers may differ in patience, environmental identity, price search ability, and trust in delivery promises. Future empirical work can use clickstream data to separate consumers who wait for price discounts from consumers who delay because delivery time is uncertain.

Another limitation is that the model assumes enforceable contracts. In practice, enforcement depends on data quality, cyber security, carbon-label standards, and institutional trust. Future research should compare traditional audits, platform records, blockchain-based records, and third-party carbon verification as alternative governance tools.

8. Conclusion

This article developed a green innovation contract framework for carbon-sensitive e-commerce supply chains with strategic waiting consumers. The key argument is that carbon reduction, dynamic pricing, and delivery-time control should be governed jointly because consumers evaluate these attributes together when deciding whether to buy now or wait.

The simulation results show that wholesale contracts underperform when green demand benefits are shared but green and delivery investments are not coordinated. Cost-sharing contracts improve outcomes, but their effectiveness depends on carbon sensitivity and consumer patience. Composite performance contracts create the broadest mutual-gain region because they connect manufacturer support to verified carbon and delivery outcomes.

The study contributes to green business innovation by reframing carbon-aware fulfillment as a contract governance problem. It also contributes to e-commerce operations by showing that delivery-time control is not only a logistics decision but also a behavioral instrument for managing strategic waiting. Finally, it contributes to digital supply chain research by showing how platform data can support enforceable sustainability contracts.

The practical message is straightforward: green e-commerce requires more than low-carbon products and fast delivery promises. It requires contracts that decide who pays, who verifies, and who benefits when carbon reduction and delivery reliability jointly create consumer value.

Declarations

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The simulation data used in this study are generated from the parameter ranges reported in the article and can be reproduced from the model equations.

Author Contributions

Conceptualization, L.H. and M.Z.; methodology, S.W.; simulation and visualization, H.Y.; writing-original draft, L.H.; writing-review and editing, all authors; supervision, M.Z.

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