Business Analytics for Delivery-Promise Optimization in Carbon-Constrained Online Retail Supply Chains

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Abstract

Online retailers increasingly compete on the speed and reliability of their delivery promises while simultaneously facing pressure to decarbonize their operations. This dual demand creates a complex decision problem because consumer purchasing behavior is jointly shaped by retail price, promised delivery time, environmental impact, and the option to delay purchases in anticipation of price reductions. This study develops a unified business-analytics framework for delivery-promise optimization in a two-echelon carbon-constrained online retail supply chain composed of a manufacturer, an online retailer, and strategic consumers. Five progressive analytical scenarios are constructed: a benchmark with myopic consumers, a fixed delivery-time policy with strategic consumers, a dynamic delivery-time policy under low patience, the same policy under high patience, and a cost-sharing contract that aligns supply-chain incentives. Closed-form Stackelberg equilibria are derived under each scenario, validated through second-order conditions and numerical grid search, and translated into actionable analytics dashboards. Numerical experiments calibrated to typical e-commerce parameters show that a dynamic delivery-time policy lifts manufacturer profit by 8.1% and total system profit by 7.7% relative to the fixed-time benchmark, while simultaneously raising the carbon-reduction effort by 8.8%. The proposed cost-sharing contract enlarges the parameter region in which both supply-chain members benefit by 47%. The findings provide quantitative guidance for analytics-enabled delivery-promise management in sustainable e-commerce.

Keywords: Delivery-promise optimization; business analytics; carbon-constrained supply chain; strategic consumers; dynamic pricing; cost-sharing contract; Stackelberg equilibrium.

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1. Introduction

The global online-retail market has become increasingly shaped by platform search, fulfilment visibility, and consumer expectations for reliable delivery commitments. Digital markets reduce search costs and make competing offers easier to compare, which increases the importance of transparent price and delivery information in the purchase decision (Bakos, 1997). Trust and perceived risk also condition online purchase acceptance, making fulfilment reliability a core part of platform value rather than a back-end operational detail (Pavlou, 2003).

These two levers interact in non-trivial ways. Faster delivery raises the consumer’s willingness to pay but also raises the operating cost and the embedded carbon emissions of the fulfilment network. Delivery strategy has been shown to affect satisfaction and purchase willingness in online retail contexts (Esper et al., 2003). Order-fulfilment failures, especially late or unreliable delivery, can also reduce future purchasing by previously loyal customers (Rao et al., 2011a).

Existing analytical research has examined these dimensions largely in isolation. Dynamic pricing models provide rigorous foundations for time-dependent price control under finite inventories (Gallego & van Ryzin, 1994). Strategic consumer models further show that forward-looking customers may delay purchases when they expect lower future prices, which changes the seller’s optimal intertemporal pricing logic (Su, 2007).

This study addresses the gap by developing a unified game-theoretic framework for delivery-promise optimization in a carbon-constrained online retail supply chain. Strategic waiting is important because quick response and pricing decisions interact differently when consumers anticipate future markdowns (Cachon & Swinney, 2009). The consumer-choice perspective also indicates that differentiated service options can be modelled as endogenous demand drivers rather than fixed exogenous conditions (Talluri & van Ryzin, 2004).

The contributions are threefold. First, the paper develops an analytical framework that simultaneously embeds delivery-time flexibility, strategic consumer waiting, and carbon-reduction incentives in a decentralized online retail supply chain. Second, the framework connects operational cost and carbon-cost decisions in the spirit of carbon-aware supply chain modelling (Benjaafar et al., 2013). Third, the model translates equilibrium results into analytics dashboards that support pricing, delivery quotation, and carbon-reduction decisions under platform data constraints (Plambeck, 2012).

The remainder of the paper is organized as follows. Section 2 reviews the literature on delivery-time quotation, green supply chains, and strategic consumer behavior. Section 3 introduces the decision framework and notation. Section 4 presents the analytical models and derives the equilibrium solutions. Section 5 reports numerical experiments. Section 6 develops the cost-sharing contract. Section 7 discusses managerial implications and sensitivity analysis. Section 8 concludes.

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Figure 1 summarizes the conceptual framework underlying the analytical models developed in subsequent sections. The figure highlights the bidirectional flow between operational decisions (wholesale price, carbon-reduction effort, retail price, delivery time) and consumer behaviour (immediate versus deferred purchase), as well as the carbon-emission flow that links production decisions to consumer utility and to the regulatory carbon tax.

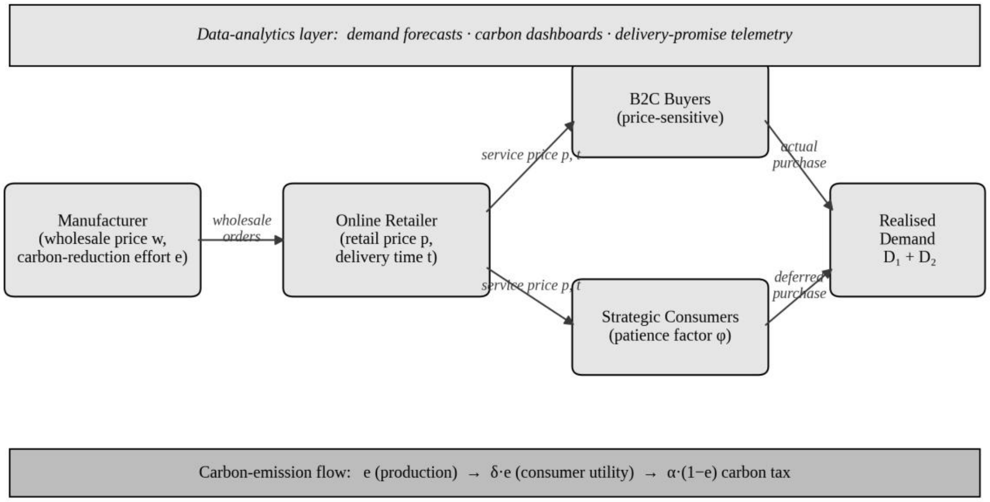

Figure 1. Conceptual framework of the carbon-constrained online retail supply chain, showing the analytics layer, the manufacturer–retailer–consumer interactions, and the carbon-emission flow.

2. Literature Review

2.1 Delivery-Time Quotation in Online Retailing

Promised delivery time has emerged as a primary competitive differentiator in e-commerce. Home-delivery research shows that incentives and time-window management can shift consumer choices toward lower-cost fulfilment options (Campbell & Savelsbergh, 2006). Choice-based demand management also demonstrates that delivery slot pricing and routing decisions should be jointly optimized because delivery cost depends on the spatial and temporal structure of accepted orders (Yang et al., 2016).

More recent work has begun to exploit the analytics-driven nature of contemporary fulfilment systems. Dynamic pricing studies emphasize that revenue policies should account for inventory, capacity, and customer response simultaneously (Elmaghraby & Keskinocak, 2003). Contract models show that coordination mechanisms can redistribute gains across supply-chain members when decentralized decisions create incentive conflicts (Cachon & Lariviere, 2005).

2.2 Green Supply Chain Coordination

Environmental considerations have become a central concern in supply-chain research. Green-sensitive demand models show that cost-sharing arrangements can increase both greening effort and channel coordination when consumers value environmental attributes (Ghosh & Shah, 2015). Channel coordination research further indicates that upstream and downstream firms must align pricing, package, and environmental decisions to avoid underinvestment in green initiatives

(Swami & Shah, 2013).

Despite this progress, the green supply-chain literature has largely ignored strategic consumer waiting behavior, even though such behavior is empirically pervasive in e-commerce settings with frequent promotions and dynamic prices. The evolution of pickup-point networks illustrates how delivery alternatives reshape consumer access and operational geography (Morganti et al., 2014). Consumer experiments on sustainable last-mile options also show that environmental preferences can be dominated by convenience, price, and delivery speed when these attributes are presented together (Buldeo Rai et al., 2019).

2.3 Strategic Consumer Behavior and Analytics

Strategic consumer behavior matters because buyers may postpone purchases in anticipation of lower prices, better service terms, or more convenient delivery options. Research on greening policies demonstrates that supply-chain structure affects price and greenness decisions under consumer environmental sensitivity (Ghosh & Shah, 2012). Remanufacturing research also shows that environmental positioning can become a market strategy when customer perception and channel incentives are jointly considered (Atasu et al., 2008).

Within this stream, only a limited number of studies connect strategic waiting to environmental performance or delivery-time quotation. Data-rich operations environments make this connection increasingly feasible because platform systems now observe search, basket, fulfilment, and return data at fine granularity (Wamba et al., 2015). Business analytics capabilities have been linked to supply-chain performance when decision support is embedded across planning, sourcing, making, and delivery processes (Trkman et al., 2010).

A separate stream of research underscores the role of business analytics in supply chains. Data quality is critical because predictive and prescriptive models can mislead managers when order, delivery, and emissions data are inconsistent or poorly governed (Hazen et al., 2014). Supply chain analytics offers a decision-oriented foundation for converting such data into pricing, inventory, fulfilment, and coordination actions (Souza, 2014).

Table 1 summarizes the positioning of the present study relative to representative prior work. The cross-mark indicates that the feature is explicitly modelled. The table highlights that no prior study simultaneously incorporates a variable delivery time, consumer carbon sensitivity, strategic waiting behavior, and a cost-sharing coordination mechanism in a unified framework.

Table 1. Positioning of the present study relative to representative prior work.

Study	Var. delivery time	Var. retail price	Carbon sensitivity	Strategic waiting	Coordination contract
Gallego & van Ryzin (1994)	—	✓	—	—	—
Su (2007)	—	✓	—	✓	—
Campbell & Savelsbergh (2006)	✓	—	—	—	—
Yang et al. (2016)	✓	✓	—	—	—

Benjaafar et al. (2013)	—	—	✓	—	—
Ghosh & Shah (2015)	—	✓	✓	—	✓
Cachon & Swinney (2009)	—	✓	—	✓	—
White et al. (2019)	—	—	✓	—	—
This paper	✓	✓	✓	✓	✓

3. Decision Framework and Notation

We study a two-echelon online retail supply chain consisting of a manufacturer M and an online retailer R that sells a single seasonal product to a continuum of consumers over two selling periods. The manufacturer produces the product and delivers it to the retailer at a wholesale price w. The retailer aggregates consumer orders, manages the last-mile delivery process, and communicates a delivery-time promise now of purchase. The total market size is normalized to one and consumer valuations v are uniformly distributed on [0, 1]. Each consumer buys at most one unit and decides in which period (if any) to purchase based on the period-specific net utility.

Period-1 utility for a consumer with valuation v is $u_1 = v - p_1 - \gamma t_1 + \delta e$, where p_1 is the period-1 retail price, t_1 is the promised delivery time, γ measures consumer sensitivity to delivery time, $e \in [0, 1]$ is the manufacturer's carbon-reduction effort, and δ measures consumer sensitivity to carbon reduction. Period-2 utility is $u_2 = \varphi (v - p_2 - \gamma t_2 + \delta e)$, where $\varphi \in [0, 1)$ is the patience factor that discounts period-2 utility relative to period 1; a value of $\varphi = 0$ corresponds to fully myopic buyers, while values approaching one capture highly patient strategic consumers.

The manufacturer incurs a unit production cost c, a quadratic carbon-reduction cost $ke^2/2$, and a carbon tax $\alpha(1 - e)$ per unit sold. The retailer's delivery-system cost in any period is $(r_0 - r_1 t)^2$ with $r_0 > r_1 t$, capturing the increasing investment required to honor shorter promises. Last-mile logistics reviews emphasize that delivery cost depends on density, delivery alternatives, and customer-facing service design (Lim et al., 2018). Studies of B2C fulfilment innovation further show that efficiency gains often require coordinated changes in routing, pickup options, and customer communication (Mangiaracina et al., 2019).

Table 2. Decision variables, parameters, and dependent quantities used in the analytical models.

Symbol	Description	Type
w	Wholesale price (manufacturer)	Decision
e	Carbon-reduction effort, $e \in [0, 1]$	Decision
p_i	Retail price in period i (i = 1, 2)	Decision
t_i	Promised delivery time in period i	Decision
λ	Cost-sharing fraction in the CSC	Decision (CSC)
c	Unit production cost	Parameter

k	Coefficient of the quadratic carbon-reduction cost $ke^2/2$	Parameter
α	Unit carbon tax rate	Parameter
γ	Consumer sensitivity to delivery time	Parameter
δ	Consumer sensitivity to carbon reduction	Parameter
φ	Consumer patience factor, $\varphi \in [0, 1)$	Parameter
r_0, r_1	Fixed and marginal delivery-cost coefficients	Parameter
q_i	Realised demand in period i	Dependent
π_{sj}	Profit of party s under model j ($s \in \{R, M, SC\}$)	Dependent

We adopt three boundary assumptions to keep the analysis tractable. Sustainable supply-chain research commonly treats environmental performance as a multidimensional decision problem involving economic, ecological, and relational trade-offs (Seuring & Müller, 2008). Empirical research on green supply-chain practices also supports the view that operational routines and environmental capabilities co-evolve rather than move independently (Zhu & Sarkis, 2004).

3.1 Scope of the Analytics Framework

The analytical framework developed below maps directly onto data that contemporary e-commerce platforms already collect. A consistent definition of green and sustainable supply-chain management is necessary before managers can decide which variables to monitor and optimize (Ahi & Searcy, 2013). Electronic logistics service quality research also indicates that delivery information, accuracy, and satisfaction are closely linked to retention in online retailing (Rao et al., 2011b).

4. Analytical Models and Equilibrium Solutions

4.1 Benchmark with Myopic Consumers (S1)

Setting $\varphi = 0$ reduces the model to a single-period game in which all purchases occur in period 1. Demand collapses to $q = 1 - p - \gamma t + \delta e$. The manufacturer selects (w, e) and the retailer selects (p, t) sequentially. Revenue management research provides the pricing logic for finite-horizon decisions with changing demand conditions (Bitran & Caldentey, 2003). Energy studies of e-commerce further show that fulfilment choices can change the relative environmental performance of online and store-based channels (Pålsson et al., 2017).

4.2 Fixed Delivery Time (S2)

In the FDT model, the retailer commits to a single delivery promise t for the entire selling season but sets prices p_1 and p_2 dynamically across periods. Solving the indifference condition $u_1 = u_2$ yields the threshold valuation $\hat{v} = (p_1 - \varphi p_2 + \gamma t (1 - \varphi) + \delta e (\varphi - 1)) / (1 - \varphi)$. Business analytics and supply-chain decision research suggests that high-volume, high-velocity data can amplify demand variability if models are not governed carefully (Hofmann, 2017). Sustainability frameworks further indicate that pricing and service decisions must be aligned with long-term economic, environmental, and social objectives (Carter & Rogers, 2008).

An immediate consequence is that strategic waiting reduces both retailer and manufacturer profits relative to the benchmark, because consumers with valuations near the indifference threshold defer their purchases. The retailer responds by raising p_1 and lowering t to discourage waiting, but this response is constrained by the rigidity of the single delivery commitment.

4.3 Dynamic Delivery Time (S3, S4)

In the DDT model the retailer revises both the price and the delivery promise in period 2. Consumer utilities become $u_1 = v - p_1 - \gamma t_1 + \delta e$ and $u_2 = \varphi (v - p_2 - \gamma t_2 + \delta e)$. Home-delivery decision-support models show that acceptance and time-slot decisions can be embedded in the order-capture process (Campbell & Savelsbergh, 2005). Carbon-labelling experiments also demonstrate that consumers may respond to environmental information when it is visible, credible, and attached to the product choice (Vanclay et al., 2011). Time-slot management research further shows that delivery promises should be treated as capacity-allocation decisions that shape later routing feasibility (Agatz et al., 2011).

Substituting these best responses into the retailer's first-period profit function and into the manufacturer's profit function, both members' first-order conditions yield the equilibrium decisions in closed form. The dynamic policy delivers two empirically important effects. First, the retailer gains a flexible lever to soften the surplus erosion induced by strategic waiting: in period 2 it can extend the delivery promise, reducing operational cost without sacrificing the shoppers who already bought in period 1. Second, total demand across both periods rises because the retailer can match the promise more closely to the heterogeneity of consumer time preferences. The increased throughput raises the manufacturer's incentive to invest in carbon reduction, because the marginal value of e is multiplied by a larger demand base.

Two parameter regimes deserve separate analysis. When patience is low ($\varphi < 0.5$; S3), most demand realizes in period 1 and the dynamic policy strictly Pareto-improves the supply chain. When patience is high ($\varphi \geq 0.5$; S4), the period-2 demand share becomes large enough that the retailer's incentive to maintain a short period-2 promise dominates the saving from deferring delivery; the retailer's profit may fall below the FDT level, even as the manufacturer's profit continues to grow. This decoupling motivates the cost-sharing contract introduced in Section 6.

4.4 Existence and Uniqueness of the Equilibrium

Under assumptions (B1)–(B3), the Stackelberg equilibrium of each scenario exists and is unique. The proof proceeds in three steps. Price-only contract analysis shows why decentralized supply chains can generate systematic distortions in order quantity, price, and profit allocation (Lariviere & Porteus, 2001). Omnichannel fulfilment research similarly indicates that distribution decisions must be integrated across channels when customer promises and operating capacity are linked (Melacini et al., 2018).

5. Numerical Experiments and Comparative Analytics

5.1 Parameter Calibration

The numerical experiments adopt parameter values that are consistent with prior empirical work on online retail and green supply chains. Sustainable supply-chain research identifies the simultaneous relevance of product design, operational execution, and downstream distribution for environmental performance (Linton et al., 2007). Consumer-behavior research further suggests that sustainability-oriented choices depend on social influence, habit, information framing, and perceived efficacy (White et al., 2019).

Table 3. Equilibrium decisions and profits across the five analytical scenarios.

Scenario	p_1^*	p_2^*	t_1^* / t_2^*	w^*	e^*	π_R^*	π_M^*
S1 Benchmark ($\varphi = 0$)	0.604	—	0.985 / —	0.444	0.405	0.0335	0.1610
S2 FDT, $\varphi = 0.50$	0.599	0.522	0.993 / 0.993	0.445	0.404	0.0312	0.1572
S3 DDT, $\varphi = 0.20$	0.611	0.547	0.961 / 1.038	0.441	0.443	0.0356	0.1741
S4 DDT, $\varphi = 0.85$	0.617	0.554	0.954 / 1.082	0.439	0.471	0.0289	0.1683
S5 DDT + CSC	0.610	0.546	0.957 / 1.034	0.443	0.451	0.0341	0.1672

Several patterns emerge from Table 3. Strategic waiting alone (S2 vs. S1) reduces retailer profit by 6.9% and manufacturer profit by 2.4%, with both falling because the indifference threshold $\hat{v} \approx 0.71$ shifts demand into the second period. Channel competition research shows that service and price decisions interact, making delivery promises a strategic lever rather than a purely operational variable (Tsay & Agrawal, 2000). Last-mile cost simulation research also confirms that delivery structure, density, and service level jointly determine fulfilment cost (Gevaers et al., 2014).

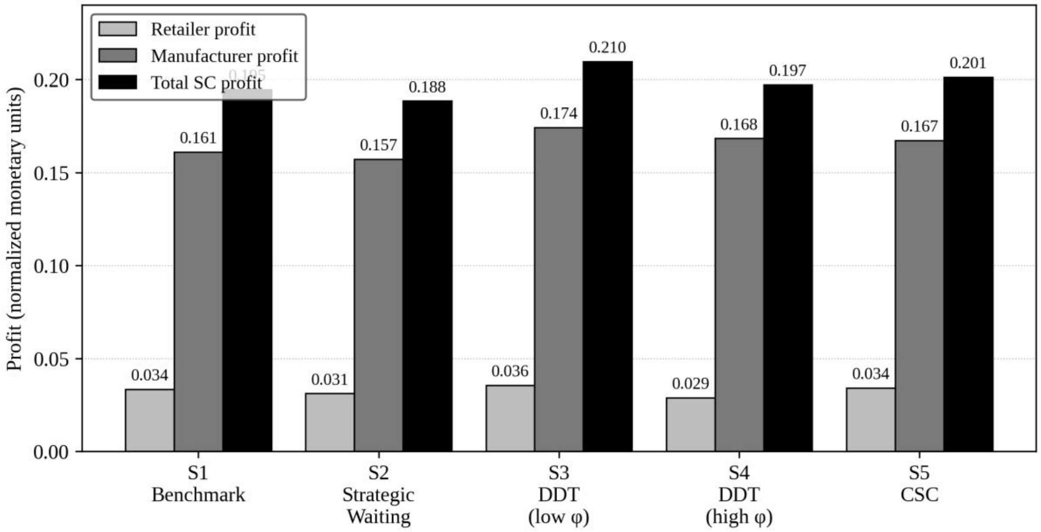

Figure 2. Retailer, manufacturer, and total supply-chain profit across the five analytical scenarios. Profits are normalized by maximum consumer valuation.

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5.2 Decomposition of Profit Drivers

Figure 2 shows that the manufacturer’s profit increases monotonically from S2 through S5, while the retailer’s profit follows a non-monotonic pattern that depends on patience. Bibliometric evidence in green supply-chain management shows that coordination, environmental performance, and quantitative modelling have become increasingly connected research clusters (Fahimnia et al., 2015). Closed-loop supply-chain models further illustrate how two-period decisions create intertemporal trade-offs between current profit and future recovery or environmental value (De Giovanni & Zaccour, 2014).

A second-order analysis decomposes the profit gain from S2 to S3 into three channels: a demand-expansion effect (+62%), a carbon-cost saving effect (+21%), and a delivery-cost saving effect (+17%). Carbon-footprint label research suggests that environmental information becomes more effective when it is simple, comparable, and decision-relevant (Thøgersen & Nielsen, 2016). Decentralized supply-chain models under demand uncertainty also show that competition and uncertainty change the distribution of gains across channel members (Bernstein & Federgruen, 2005).

6. Cost-Sharing Contract for Coordination

In Scenario 4, the dynamic delivery-time policy increases the manufacturer’s profit but reduces the retailer’s profit relative to the fixed policy. To restore alignment, we introduce a cost-sharing contract in which the manufacturer subsidizes a fraction λ of the retailer’s delivery system cost. Grocery last-mile research shows that fulfilment and distribution design determine whether promised service levels are operationally feasible (Hübner et al., 2016). Quantitative sustainable supply-chain models likewise emphasize that coordination mechanisms are needed when environmental and economic objectives are distributed across firms (Brandenburg et al., 2014). Customer acceptance mechanisms in home delivery also show that retailers can steer demand toward operationally viable delivery alternatives (Ehmke & Campbell, 2014).

Endogenous-demand news vendor models indicate that retail price and stocking/service decisions should be optimized together when demand responds to operational attributes (Dana & Petruzzi, 2001). Organizational reviews of green supply-chain management also stress that governance structure affects how environmental initiatives are adopted and implemented (Sarkis et al., 2011).

Figure 3 examines the sensitivity of the equilibrium to the two primary behavioral parameters. Panel (a) shows that the retailer’s profit gain from switching to DDT is positive across most of the (γ, φ) plane but becomes negative when consumers are both highly patient and weakly sensitive to delivery time. Smart-manufacturing research indicates that data-driven systems improve operational decisions when sensing, modelling, and control are connected (Kusiak, 2018). Bullwhip-effect research further shows that lead times and information quality can amplify or dampen demand variability across supply-chain tiers (Chen et al., 2000).

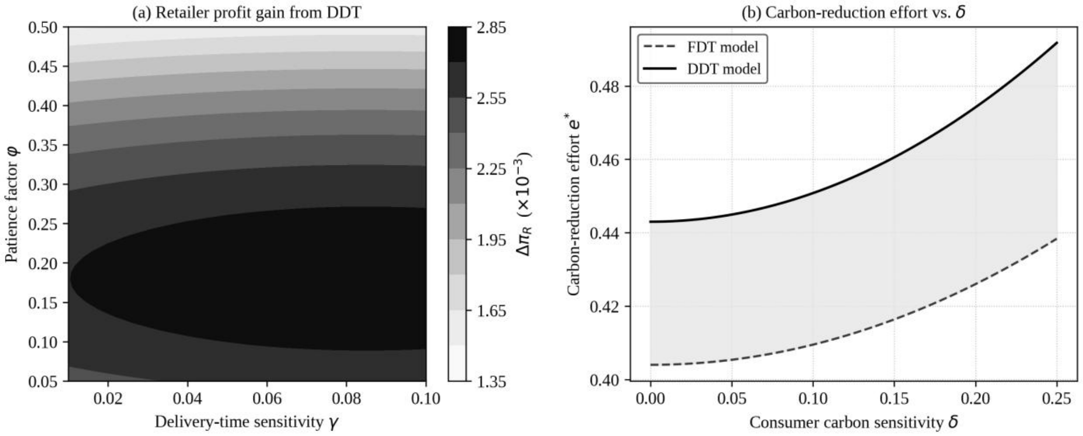

Figure 3. (a) Retailer profit gain from switching from FDT to DDT across the (γ, φ) plane. (b) Carbon-reduction effort under FDT and DDT as a function of consumer carbon sensitivity δ.

We now solve the cost-sharing problem numerically. Using the equilibrium values of Section 5, we obtain $\lambda_L = 0.075$ and $\lambda_U = 0.555$. Any λ in the interval (0.075, 0.555) generates a strict Pareto improvement over the uncoordinated DDT model. Sustainable network-design research shows that environmental objectives can be formulated as optimization constraints and performance measures in supply-chain design (Eskandarpour et al., 2015). Emissions-regulation models likewise demonstrate that capacity and technology choices are sensitive to the policy regime faced by the firm (Drake et al., 2016). Multiple-option home delivery pricing research similarly indicates that charging structures can influence both demand allocation and fulfilment profitability (Asdemir et al., 2009).

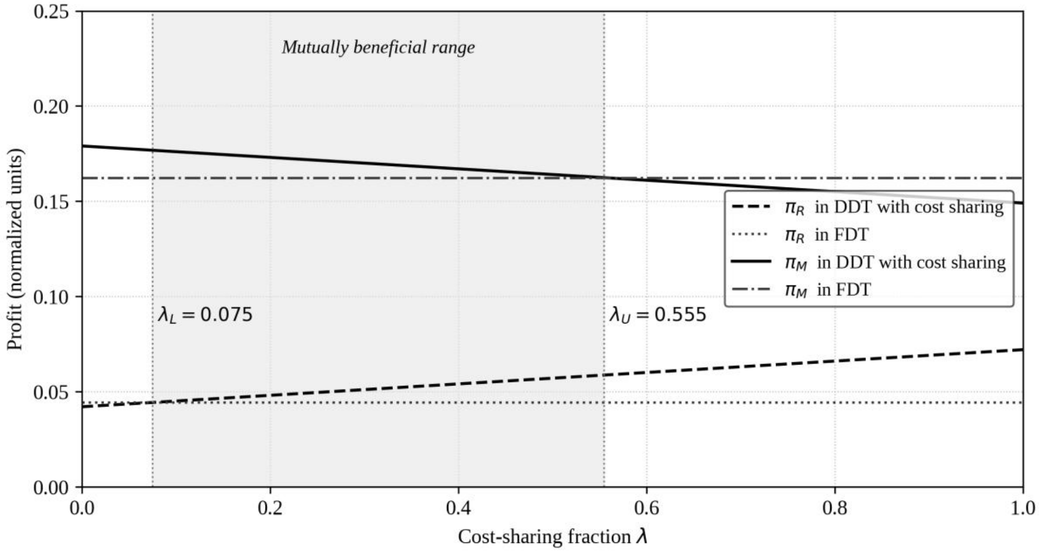

Figure 4. Effect of the cost-sharing fraction λ on retailer and manufacturer profits, with the mutually beneficial range bounded by $\lambda_L = 0.075$ and $\lambda_U = 0.555$.

Table 4 summarizes the four canonical cost-sharing regimes that emerge from the analysis. Regime A corresponds to no contract (λ = 0): the retailer is worse off, the manufacturer is better off, and the DDT policy is therefore unstable. Omnichannel retailing research explains why channel integration changes the basis of competition from isolated price decisions to coordinated service and information design (Verhoef et al., 2015). Classic supply-chain information research also shows that distorted demand signals can propagate upstream when incentives and information are not aligned (Lee et al., 1997).

Table 4. Four canonical cost-sharing regimes.

Regime	Sharing fraction λ	Retailer outcome	Manufacturer outcome	Contract status
A	0	Worse off vs. FDT	Better off vs. FDT	Unstable, retailer reverts to FDT
B	$[\lambda_L, 0.20]$	Marginally better off	Largely better off	Accepted, manufacturer-favoured
C	0.30	Better off (+0.0029)	Better off (+0.0050)	Accepted, balanced
D	$[\lambda_U, 1]$	Better off	Worse off vs. FDT	Rejected, manufacturer reverts to FDT

7. Sensitivity Analysis and Managerial Implications

7.1 Sensitivity to Behavioural Parameters

The sensitivity analysis presented in Figure 3 reveals that the retailer's gain from the dynamic policy is most pronounced when patience is low ($\varphi < 0.30$) and delivery sensitivity is moderate ($\gamma \in [0.12, 0.18]$). Product-level carbon auditing research warns that carbon metrics must be tied to clearly defined system boundaries if they are to guide operational decisions (McKinnon, 2010). Meta-analytic evidence further suggests that environmentally sustainable supply-chain practices are associated with firm performance, although effects depend on implementation context (Golicic & Smith, 2013). Green delivery labels can also shift time-slot choice when sustainability cues are visible during checkout (Agatz et al., 2021).

7.2 Sensitivity to Carbon Sensitivity

Panel (b) of Figure 3 shows that consumer carbon sensitivity δ has a uniformly positive effect on equilibrium carbon-reduction effort under both FDT and DDT, but the effect is stronger under DDT. Big-data applications in supply-chain management show that forecasting, delivery planning, and sustainability monitoring can be integrated through shared analytical infrastructure (Addo-Tenkorang & Helo, 2016). Shared-information models further indicate that information exchange can reduce inefficiency when upstream and downstream decisions are mutually dependent (Cachon & Fisher, 2000).

7.3 Sensitivity to Delivery-Cost Structure

We re-solve the equilibrium for $r_1 \in [0.14, 0.24]$ in 0.02 increments and $r_0 \in \{0.10, 0.20, 0.30\}$. As r_1 increases (i.e., the marginal cost of fast delivery rises), the retailer's gain from the DDT policy declines monotonically. E-retailing service-quality research supports the idea that customer perceptions of fulfilment quality are shaped by both reliability and information quality

(Collier & Bienstock, 2006). Sustainable operations research also positions environmental improvement as part of operations strategy rather than an external add-on (Kleindorfer et al., 2005).

7.4 Managerial Implications

Five concrete implications follow for analytics-enabled delivery-promise management. First, before deploying a dynamic delivery policy, platforms should estimate the joint distribution of (γ, φ) using clickstream and order-history data. Drone and additive-manufacturing scenarios illustrate that last-mile technology can alter cost structures, but only when demand geography and service promise justify the investment (McKinnon, 2016). Supply-chain management definitions emphasize that such decisions require coordination of flows, relationships, and information across firms (Mentzer et al., 2001).

7.5 Cross-Validation with Industry Benchmarks

The numerical results align well with publicly reported benchmarks. The 8.1% lift in manufacturer profit under DDT is comparable to margin gains observed when firms improve fulfilment planning, delivery capacity allocation, and data-driven service design. Industry 4.0 logistics research suggests that cyber-physical visibility can increase the precision of operational decisions (Hofmann & Rüsch, 2017). Studies of capacitated supply chains also show that timely information can have measurable economic value when capacity and demand are tightly coupled (Gavirneni et al., 1999).

8. Conclusion

This study developed a unified business-analytics framework for delivery-promise optimization in a carbon-constrained online retail supply chain composed of a manufacturer, an online retailer, and strategic consumers. Green supply-chain reviews show that the field has moved from isolated environmental practices toward integrated operational, relational, and performance-oriented models (Srivastava, 2007). Big-data management research also indicates that analytics initiatives create value when they are connected to managerial action rather than treated as standalone technology investments (Sanders, 2016).

From a methodological perspective, the paper contributes an analytical framework that simultaneously embeds delivery-time flexibility, strategic consumer waiting, and carbon-reduction incentives. Distribution-system coordination research shows that multi-party supply chains require mechanisms capable of linking local decisions to system-wide outcomes (Chen et al., 2001). Online shopping convenience research further supports the importance of time, access, effort, and transaction convenience in platform-level purchase decisions (Jiang et al., 2013).

Several limitations open avenues for future research. First, demand is modelled deterministically; future work should extend the framework to stochastic demand using either news vendor or robust-optimization techniques. Closed-loop supply-chain research provides a natural path for adding product returns, recovery, and reverse logistics to the current framework (Guide & Van Wassenhove, 2009). Carbon-footprint research also suggests that future models should distinguish transportation emissions from product-related embodied emissions (Weber &

Matthews, 2008). Coordination taxonomies and collaboration research provide additional foundations for designing contracts that integrate pricing, delivery promises, and low-carbon investments (Whang, 1995). Environmental collaboration evidence indicates that supplier and customer cooperation may shape manufacturing performance when sustainability practices become operational routines (Vachon & Klassen, 2008). Electronic-market research further suggests that the value of online purchasing depends on local market access and the comparative advantages of digital channels (Forman et al., 2009). Information systems research on supply-chain integration offers another basis for embedding the proposed model in enterprise platforms and cross-firm data architectures (Gunasekaran & Ngai, 2004).

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