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A Prospect Theory Framework for Pricing Airline Terms & Conditions Ancillaries

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Abstract

Airline Terms & Conditions (T&C) ancillaries such as change waivers, cancellation-for-cash protections, and cancellation-for-credit assurances represent a rapidly growing revenue category in airline retailing. Traditional pricing approaches rely heavily on heuristics—percentage-of-fare rules, fixed markups, or simplified expected-value calculations. These methods treat travelers as objective risk evaluators, ignoring behavioral biases documented in psychology and insurance economics. Prospect Theory (PT), particularly its cumulative formulation (CPT), provides a mathematically grounded framework for modeling traveler perceptions of risk, loss, and uncertainty. This paper develops a structural CPT framework tailored to airline T&C ancillaries and shows how its components integrate into practical pricing workflows used by modern airline retail systems.

Keywords: Prospect Theory; Cumulative Prospect Theory; Airline Ancillaries; Behavioral Pricing; Terms & Conditions Ancillaries; Revenue Management

INTRODUCTION

Airline ancillary products have evolved from optional add-ons into a major revenue pillar, with several carriers generating billions annually from non-fare items. While early ancillaries focused on tangible attributes such as seats, baggage, or onboard services, recent advancements in airline retailing have open up a new gateway to price the non-tangible attributes like Terms & Conditions (T&C) —change waivers, refund protections, cancellation-for-credit, and refund ladders. These ancillaries play a unique role.

Unlike merchandising ancillaries such as seats or bags, T&C products do not deliver consumption utility. Instead, they function as risk-transfer instruments: the traveler pays a known upfront fee to avoid an uncertain future penalty or loss. From an economic perspective, these products align closely with small-dollar insurance contracts and warranty products. Their valuation depends not on realized usage, but on perceived exposure to disruption risk and the psychological trade-off between a sure loss today and a contingent gain tomorrow.

Despite this insurance-like structure, pricing in the airline industry remains dominated by legacy heuristics. A fee might be set to a round number, a fixed percentage of fare, or a simplified expected-value calculation. These approaches implicitly assume that travelers evaluate risk objectively, integrate probabilities linearly, and treat upfront fees and future penalties symmetrically. Nevertheless the decades of behavioral research contradict this assumption. Empirical evidence shows that travelers overweight low-probability risks, experience upfront payments as disproportionately painful, and discount future refunds depending on framing and mental accounting. Classical utility and expected-value pricing fail to capture these dynamics.

This limitation has become increasingly consequential in the offer-order retailing paradigm, where airlines dynamically assemble and price bundles of fares, ancillaries, and contractual terms as per passenger preferences. In this environment, T&C products are no longer static mandatory items, but strategic levers that influence conversion, upsell, and customer surplus extraction. Pricing errors – either underpricing due to underestimated behavioral demand or overpricing due to misjudged risk sensitivity – can lead to substantial revenue leakage at scale. Yet existing airline revenue management models provide little guidance on how to price contractual flexibility when demand is shaped by behavioral responses to risk rather than consumption utility.

Prospect Theory provides a more behaviorally grounded lens, particularly suited to decisions where travelers balance a certain upfront fee against an uncertain but potentially costly future outcome. Building on the original formulation by Kahneman and Tversky (1979) [1] and its cumulative extension (1992) [2], this model introduces three principles highly relevant to airline T&C decisions: (i) reference dependence, (ii) loss aversion, and (iii) nonlinear probability weighting. When a traveler evaluates a change-fee waiver, the upfront fee is coded as a sure loss relative to the fare reference point, while the avoided

penalty is coded as a gain only in the event of disruption. The subjective difference between these outcomes—magnified by probability distortion—determines willingness to pay.

This paper develops a comprehensive Prospect-theoretic pricing framework for airline Terms & Conditions (T&C) ancillaries that treats contractual flexibility as a behaviorally valued risk-transfer product rather than a traditional mandatory service. Building on Cumulative Prospect Theory, the framework formalizes how travelers evaluate the trade-off between a certain upfront fee and uncertain future penalties, incorporating reference dependence, loss aversion, nonlinear probability weighting, and ambiguity in disruption risk. Unlike prior airline pricing models that assume objective risk evaluation, the proposed approach explicitly models how perceived—not actuarial—risk shapes willingness to pay for refundability, change waivers, and cancellation protections.

Beyond establishing behavioral foundations, the paper translates Prospect Theory into an operational pricing methodology suitable for modern airline retail systems. The model derives closed-form CPT pricing expressions for single-event protections, multi-outcome refund ladders, and bundled coverage across multiple correlated disruption events. It further extends the framework to incorporate ambiguity aversion, mental accounting for travel credits versus cash refunds, and behavioral heterogeneity through finite-mixture specifications. These extensions allow the model to accommodate the full range of T&C products observed in practice, from simple change-fee waivers to complex refund ladders and bundled flexibility packages.

Finally, the paper proposes a complete empirical calibration and deployment pathway. It outlines how CPT parameters can be estimated using airline shopping and purchase data, how behavioral heterogeneity can be identified at scale, and how individual-level behavioral valuations can be aggregated into market-level demand and revenue curves via simulation. By linking behavioral theory, structural modeling, empirical estimation, and revenue optimization within a single unified framework, the paper provides a practical foundation for pricing T&C ancillaries in offer–order environments. In doing so, it advances airline pricing science beyond heuristic and expected-value approaches toward a behaviorally grounded, revenue-consistent methodology for monetizing contractual flexibility.

The contributions of the study are as follows:

1. No prior work provides a fully articulated Prospect-Theoretic model of T&C ancillary pricing within airline revenue management. While PT has been applied to consumer behavior in other industries, its integration into airline pricing remains unexplored.
2. Behavioral deviations observed in insurance markets—such as demand for dominated products, ambiguity aversion, and overweighting of rare events—have not been incorporated into airline models despite the clear structural parallels.
3. Existing airline ancillary research lacks a unified structural estimation framework capable of calibrating behavioral parameters using real booking and purchase data.

LITERATURE REVIEW

The literature related to airline Terms & Conditions ancillaries spans three academic domains: behavioral decision theory, insurance economics, and airline pricing science. This section synthesizes insights from each domain to establish the theoretical and empirical foundations required for a Prospect-Theoretic model of flexibility-product pricing.

Prospect Theory and Behavioral Decision-Making

Prospect Theory (PT), introduced by Kahneman and Tversky [1] and later extended into Cumulative Prospect Theory (CPT) [2], provides a reference-dependent framework in which individuals evaluate outcomes not in absolute wealth but relative to a psychologically meaningful benchmark. In the airline context, this benchmark corresponds naturally to the base fare without protection. CPT formalizes two key components that are central to understanding traveler demand for flexibility: a value function exhibiting loss aversion and diminishing sensitivity, and a probability weighting function that transforms objective event probabilities into subjective decision weights.

The value function proposed in the original formulation is concave for gains and convex for losses, with losses multiplied by a factor λ greater than one. Empirical studies consistently estimate λ to lie between 1.8 and 2.8 [3], indicating that losses are psychologically about twice as impactful as comparable gains. This asymmetry is directly relevant for T&C ancillaries because the ancillary fee is always encoded as a sure loss at the moment of purchase, while the benefit of the ancillary is contingent and prospective. Travelers therefore require a substantially higher perceived benefit in the event of disruption to compensate for the immediate disutility of the fee.

CPT also embeds a nonlinear probability weighting function, which captures systematic deviations from objective probability perception. Prelec's probability weighting formulation [4] remains the most widely validated functional form and predicts overweighting of small probabilities and underweighting of moderate and high probabilities. Across risk domains—including monetary gambles, health risks, consumer warranties, and insurance choices—experimental and field evidence shows that individuals treat low-probability adverse events as substantially more likely than they objectively are [5,6]. For airline travel, where cancellations and involuntary changes are low-probability but emotionally salient events, such distortions create strong psychological incentives to purchase protection products even when expected-value considerations alone would suggest otherwise.

Behavioral Insurance Economics

The economic literature on insurance provides the closest empirical analogue to airline T&C ancillaries. Insurance decisions involve choosing between a certain small premium and an uncertain large loss, structurally identical to the choice between purchasing or not purchasing a flight-change waiver or refund protection. However, numerous studies demonstrate that real-world insurance decisions deviate sharply from

expected utility predictions. Rabin's calibration critique [7] illustrates that the degree of risk aversion implied by small-premium insurance purchases is incompatible with any plausible globally concave utility function, suggesting that consumers' choices cannot be rationalized without invoking loss aversion or probability distortion.

Sydnor's investigation of deductible choices in homeowners' insurance [8] provides one of the clearest demonstrations of behavioral insurance demand. Homeowners routinely select extremely low deductibles that are actuarially dominated, implying a willingness to pay far above the expected savings associated with the deductible. This behavioral overpayment is consistent with a loss-averse value function in which the prospect of paying a deductible, even when unlikely, generates strong psychological discomfort.

Further work extends these findings to ambiguity and dread risks. Empirical studies demonstrate that when probabilities are ambiguous or emotionally charged—such as robbery, illness, or major travel disruption—decision-makers display even stronger deviations from rational benchmarks [9,10]. These findings extend naturally to airline T&C products. Travelers often have only vague expectations about cancellation or disruption risks, and this ambiguity—combined with the emotional salience of potential trip failure—tends to magnify perceived risk beyond actuarial levels. The resulting overweighting of small probabilities increases the subjective value of protection products independently of their actuarial properties.

Airline Ancillary Pricing Research

The literature specific to airline pricing has historically focused on seat products, baggage fees, fare families, and dynamic pricing algorithms. Although this research provides valuable insights into consumer choice modeling and revenue management, it rarely integrates behavioral economics. For example, studies on fare families and refundability [11] treat flexibility as an attribute embedded in the fare-product structure rather than a standalone insurance-like optional product. Models of refundability typically assume rational discrete-choice behavior without incorporating nonlinear probability weighting or loss aversion [12], limiting their applicability to T&C ancillary pricing.

Research on ancillary revenue optimization has expanded in recent years, but the majority of studies focus on inventory-constrained ancillaries such as seats, Wi-Fi, or bags. Few consider T&C protections, and even fewer incorporate behavioral decision-making. The existing body of airline literature therefore lacks a dedicated structural model for pricing T&C ancillaries that explicitly accounts for traveler psychology. Behavioral phenomena extensively documented in insurance and decision theory—loss aversion, diminishing sensitivity, overweighting of rare travel disruptions, mental accounting for credits—have not been integrated into airline pricing science despite their direct relevance.

METHODOLOGY AND THEORETICAL FRAMEWORK

We consider an airline retailing environment in which a traveler purchases a base fare and is offered an optional Terms & Conditions (T&C) ancillary that modifies the financial consequences of future disruptions. The ancillary provides protection against one or more uncertain events—such as itinerary changes or trip cancellation—by waiving penalties or issuing refunds or credits if a covered event occurs. If no such event occurs, the ancillary yields no realized benefit.

The traveler's decision involves a trade-off between a certain upfront payment and an uncertain contingent benefit. The ancillary price is paid with certainty at the time of purchase and is experienced as an immediate loss relative to the base fare, while the benefit of protection is realized only in disruption states. As a result, the valuation of T&C ancillaries depends on perceived risk rather than expected usage, aligning them economically with insurance-type contracts.

Let r denote the reference point corresponding to the base fare without protection. Monetary outcomes are evaluated relative to r: the ancillary price constitutes a sure loss, while avoided penalties or refunds constitute gains conditional on disruption. The traveler chooses whether to purchase the ancillary based on the subjective valuation of this trade-off.

The airline's pricing problem is to set the ancillary price to maximize expected revenue, considering how travelers perceive and evaluate risk. In offer–order retail systems, this decision is made dynamically and at scale, conditional on itinerary and customer context. This section develops the full structural Prospect-Theoretic (PT) and Cumulative Prospect-Theoretic (CPT) pricing model for airline Terms & Conditions ancillaries. It introduces the key components of the framework—formal definitions, theoretical justification, extensions for multi-event risk, heterogeneous behavioral types, mental-accounting effects, and reference-point dynamics—and explains how each element applies directly to airline pricing.

Core Prospect-Theoretic Valuation of a T&C Ancillary

We model traveler evaluation of a Terms & Conditions (T&C) ancillary using Cumulative Prospect Theory (CPT). Consistent with CPT, outcomes are evaluated relative to a reference point rather than in absolute wealth terms. In the airline context, the natural reference point r is the base fare purchased without protection. Let x denote the monetary outcome under a given state of the world. The traveler's subjective value of an outcome is given by a reference-dependent value function $v(x)$ as follows:

$$v(x) = \begin{cases} (x-r)^{\alpha} & x \geq r \\ -\lambda(x-r)^{\alpha} & x < r \end{cases}$$

where $\alpha \in (0,1)$ represents curvature of subjective value and $\lambda > 1$ captures the magnitude of loss aversion.

In the context of T&C ancillaries, since the traveler experiences the upfront fee P, the value function is $v(-P) = -\lambda P^{\alpha}$. At the same time, since the traveler experiences the avoided penalty B, the corresponding value function is $v(B) = B^{\alpha}$. Paying the ancillary price is therefore evaluated as a sure loss, while the avoidance of a penalty or receipt of a refund is evaluated as a gain that occurs only if a disruption event materializes.

CPT replaces objective probabilities with nonlinear decision weights. Let p denote the objective probability of a covered disruption. The subjective decision weight applied to this event is given by a probability weighting function $w(p)$, which captures the symmetric overweighting of low-probability events. We adopt Prelec's one-parameter weighting function:

$$w(p) = exp[-(-In\ p)^{\gamma}]$$

where $\gamma \in (0,1)$ controls the curvature and is widely used in empirical applications and generates overweighting of small probabilities typical of travel-disruption risks. The subjective probability of disruption is therefore $w(p) > p$ for small p. Similarly, the subjective weight of no disruption is $w(1-p)$, which is typically less than $1-p$.

Single-Event CPT Pricing

We begin with the simplest T&C product: protection against a single disruption event, such as trip cancellation or voluntary itinerary change. Let the ancillary provide a monetary benefit B if the protected event occurs and let p denote the probability of that event. The ancillary is offered at price P, which is paid with certainty at the time of purchase.

Under Cumulative Prospect Theory, purchasing the ancillary is evaluated as a two-branch prospect. With probability p, the disruption occurs and the traveler receives the benefit B, evaluated as a gain relative to the reference point. With probability $1-p$, no disruption occurs and the traveler experiences the loss associated with paying the ancillary price. The CPT valuation of purchasing the ancillary is therefore given by:

$$U_{\text{buy}} = w(p)\, v(B) \ + \ w(1-p)\, v(-P)$$

where

$$v(B) = B^{\alpha}, v(-P) = -\lambda P^{\alpha}.$$

Not purchasing the ancillary yields no gain or loss relative to the reference point and is normalized to zero, $U_{no-buy} = 0$. The traveler is indifferent between purchasing and not purchasing the ancillary when:

$$U_{\text{buy}} = 0 \Longrightarrow w(p)B^{\alpha} - \lambda\, w(1-p)P^{\alpha} = 0.$$

Solving for the base CPT price gives:

$$P^* = B\left(\frac{w(p)}{\lambda\, w(1-p)}\right)^{1/\alpha}$$

This expression characterizes the ancillary price at which a traveler is behaviorally indifferent between paying a sure upfront fee and remaining exposed to an uncertain future penalty. Unlike expected-value pricing, the CPT price explicitly incorporates loss aversion and nonlinear probability weighting, implying that even low-probability disruption risks can support positive willingness to pay for protection. This single-event pricing formulation serves as the baseline for the multi-outcome and multi-event extensions developed in subsequent sections.

CPT for Multi-Outcome Prospects (Refund Ladders)

Many airline Terms & Conditions products do not offer a single contingent payoff but instead specify a refund ladder consisting of multiple possible monetary outcomes. Common examples include partial cash refunds, travel credits of varying face value, or zero refund depending on the timing or nature of the disruption. These products therefore expose travelers to a multi-outcome prospect rather than the two-branch structure considered in Section 3.3.

Let the refund ladder consist of outcomes $x_1 < x_2 < \cdots < x_N$, each occurring with respective probability $p_1, p_2, \ldots, p_N$, where the outcomes may lie in either the gain or loss domain relative to the reference point. Under Cumulative Prospect Theory, travelers do not evaluate these outcomes using expected values. Instead, outcomes are ranked and assigned decision weights that depend on cumulative probabilities.

The CPT value of the benefit component of the refund ladder is given is:

$$V_{\text{benefit}} = \sum_{i=1}^{N} \pi_i\, v(x_i)\,,$$

where $v(\cdot)$ is the Prospect Theory value function and π_i are the decision weights. Let P_i^- denote the cumulative probability of loss outcomes up to and including outcome i, with loss outcomes ordered from most severe to least severs, i.e., $P_i^- = \sum_{j=1}^{i} p_j$. For outcomes in the loss domain, decision weights, π_i^- are given by

$$\pi_i^- = w(P_i^-) - w(P_{i-1}^-)$$

Similarly, P_i^+ denote the cumulative probability of gains at least as large as outcome i. For outcomes in the gain domain, the decision weights π_i^+ are given by

$$\pi_i^+ = w(P_i^+) - w(P_{i+1}^+)$$

The ancillary has an upfront cost P, which is evaluated as a sure loss

$$V_{price} = v(-P) = -\lambda P^{\alpha}$$

Thus, the total CPT utility of buying the product is

$$V_{\text{buy}} = V_{\text{benefit}} - \lambda P^{\alpha},$$

while not purchasing yields,

$$V_{\text{no-buy}} = 0.$$

The CPT-based pricing condition is obtained by setting indifference between buying and not buying:

$$V_{\text{benefit}} - \lambda P^{\alpha} = 0 \rightarrow V_{benefit} = \lambda P^{\alpha}$$

Solving for P gives the multi-outcome CPT pricing formula:

$$P^* = \left(\frac{\sum_{i=1}^{N} \pi_i \, v(x_i)}{\lambda} \right)^{1/\alpha}$$

This formulation generalizes the single-event CPT price to arbitrary refund ladders and accommodates partial refunds, stepped refund schedules, and mixtures of cash and credit outcomes. Because CPT weights outcomes nonlinearly, refund ladders with identical expected values can generate substantially different perceived valuations. As a result, CPT-based pricing provides a principled explanation for why certain refund structures outperform others despite being actuarially equivalent.

Multi-Event Protection and Correlated Risks

Many airline T&C products provide protection against several distinct events rather than a single one. For example, a flexible travel package may cover cancellation, voluntary change, and same-day operational disruption. These events are not independent in practice. Each event is associated with its own probability of occurrence and monetary consequence, and the overall value of the ancillary depends on how travelers integrate these risks.

Let $e = 1, \dots, E$ index protected events. Conditional on event e, the ancillary may generate multiple payoff outcomes indexed by $i = 1, \dots, N_e$, reflecting refund ladders, partial waivers, or credit-based compensation.

Events need not be independent. In airline operations, disruption risks are often correlated due to shared underlying causes such as weather, air-traffic control constraints, or traveler-specific uncertainty. For example, conditions that increase the likelihood of cancellation may also increase the likelihood of same-day changes.

To capture this dependence in a tractable manner, we allow joint event probabilities to reflect correlation. For two events e and f, the joint probability can be expressed as:

$$\Pr(e,f) = p_e p_f + \rho_{ef}\sqrt{p_e(1-p_e)p_f(1-p_f)}$$

where $\rho_{ef} \in [-1,1]$ measures the strength and direction of correlation. Positive correlation implies that events tend to occur together, while negative correlation reflects substitutive patterns.

Under Cumulative Prospect Theory, each protected event contributes a contingent gain evaluated using the value function and probability weighting. The CPT valuation of purchasing the ancillary is obtained by aggregating the weighted valuations of all protected events and subtracting the sure loss associated with the ancillary price:

$$V_{buy} = \sum_{e=1}^{E}\sum_{i=1}^{N_e} \pi_{e,i} v(x_{e,i}) - \lambda P^{\alpha}$$

while not purchasing yields:

$$V_{no-buy} = 0$$

The CPT-based pricing condition is therefore given by the indifference condition:

$$\sum_{e=1}^{E}\sum_{i=1}^{N_e} \pi_{e,i} v(x_{e,i}) - \lambda P^{\alpha} = 0 \rightarrow P^{*} = \left(\frac{\sum_{e=1}^{E}\sum_{i=1}^{N_e} \pi_{e,i} v(x_{e,i})}{\lambda}\right)^{1/\alpha}$$

This formulation generalizes the single-event and multi-outcome pricing results to protection products covering multiple, potentially correlated risks. Correlation affects willingness to pay by reshaping cumulative probabilities and decision weights, even when marginal event probabilities remain unchanged. Consequently, products that are actuarially similar may exhibit substantially different perceived valuations once behavioral responses to joint risk are taken into account.

Integrating Ambiguity Aversion

Event probabilities—such as the likelihood of cancellation, voluntary change, or same-day disruption—are rarely known with precision by travelers. Individuals face uncertainty not only about whether an event will occur, but also about how accurate the published or historical probabilities are. This uncertainty motivates a distinction between risk (known probabilities) and ambiguity (imprecise or unknown probabilities).

To incorporate ambiguity into the CPT framework, let the true vector of event probabilities lie within an ambiguity set:

$$\mathcal{C} \subseteq \Delta^N,$$

where $\mathcal{C}$ represents all probability vectors the traveler believes are plausible (for example, a cancellation probability between 5% and 15%, instead of a single fixed value).

Under Maxmin CPT, the traveler evaluates the ancillary by considering the worst-case CPT value across all probability vectors in $\mathcal{C}$. The ambiguity-adjusted CPT valuation is:

$$V_{\text{Amb}}(k) = \min_{p \in \mathcal{C}} V_{\text{CPT}}(k \mid p).$$

where $V_{CPT}(k|p)$ denote the Cumulative Prospect Theory valuation of ancillary contract k, computed given event probability vector p.

That is, for every admissible probability vector p, the traveler computes the CPT valuation of the prospect and then chooses the minimum value. This captures the behavior of an ambiguity-averse traveler who is concerned that the true risk of cancellation or change might be higher than estimated.

In practice, integrating ambiguity aversion increases the perceived value of protection products, as travelers who fear underestimation of risk assign greater weight to unfavorable scenarios. This framework allows airline pricing systems to reflect realistic traveler preferences when probability estimates are uncertain or volatile.

Behavioral Heterogeneity via Mixture Models

Traveler decision-making is not homogeneous. Different customers exhibit systematically different degrees of loss aversion, diminishing sensitivity, and probability distortion. These differences lead to substantial variation in how travelers perceive risk and evaluate T&C protection products.

To capture this variation, we model the population as consisting of K behavioral classes. Each class m is characterized by its own set of CPT parameters:

$$\theta_m = (\alpha_m, \lambda_m, \gamma_{mi}), m = 1, \dots, K$$

The parameter α_m governs the curvature of the value function, λ_m measures loss aversion, and γ_m controls the shape of the probability-weighting function. A class with high λ_m and strong probability distortion may purchase protection at higher prices, while another class with low λ_m may decline protection even when faced with substantial risk.

Let π_m denote the proportion of travelers belonging to class m, with:

$$\Pr(\text{type} = m) = \pi_m, \sum_{m=1}^{K} \pi_m = 1.$$

For each class, the CPT framework produces an optimal willingness-to-pay for the ancillary, denoted by $P^*(\theta_m)$. The market-level CPT price is obtained by aggregating across all behavioral classes:

$$P^*_{\text{mix}} = \sum_{m=1}^{K} \pi_m \, P^*(\theta_m) \, .$$

This mixture formulation allows pricing engines to reflect realistic heterogeneity in traveler behavior. Empirical airline booking data consistently reveal distinct risk archetypes—such as highly risk-averse leisure travelers, moderately sensitive flexible travelers, and low-aversion business travelers—each responding differently to uncertainty and protection product pricing. Incorporating these behavioral segments leads to more accurate demand forecasts and more effective personalization strategies.

EMPIRICAL CALIBRATION FRAMEWORK

This section describes the complete estimation strategy required to calibrate the Prospect-Theoretic pricing model using airline shopping, booking, and ancillary-purchase datasets. The framework integrates maximum likelihood estimation (MLE), mixture-model segmentation, and practical constraints arising in production airline pricing systems.

Data Sources and Structure

Calibrating the CPT-based pricing model requires transaction-level airline retail data that capture both traveler exposure to T&C ancillaries and subsequent purchase decisions. The estimation framework combines four primary data sources: (i) historical cancellation and change records, (ii) booking and itinerary data, (iii) ancillary purchase transactions, and (iv) session-level exposure data indicating which travelers were shown a given T&C offer.

Historical disruption records can be used to construct empirical or model-based estimates of event probabilities, such as cancellation or voluntary change likelihoods. Booking and itinerary data will provide contextual variables including fare, route, cabin, time to departure, and trip characteristics. Ancillary transaction data will contain records whether a traveler purchased a T&C product and at what price. Exposure data ensures that non-purchases are correctly interpreted as choice outcomes rather than lack of availability.

Each observation will correspond to a traveler facing a binary decision: purchase or not purchase a specific T&C ancillary contract k at price P, given an associated vector of disruption probabilities. This structure aligns directly with the CPT valuation framework developed in Section 3 and forms the basis for likelihood-based estimation of behavioral parameters.

Maximum Likelihood Estimation of CPT Parameters

Traveler purchase behavior can be modeled as a stochastic binary choice. Let $y_i \in \{0,1\}$ denote the observed decision of traveler i, where $y_i = 1$ indicates purchase of the T&C ancillary. The latent utility difference between purchasing and not purchasing the ancillary is given by:

$$\Delta U_i = w(p_i)\, B_i^{\alpha} - \lambda\, P_i^{\alpha},$$

where p_i is the disruption probability faced by traveler i, B_i is the monetary benefit realized if the protected event occurs, and P_i is the ancillary price. The parameters α and λ govern diminishing sensitivity and loss aversion, respectively, while $w(\cdot)$ denotes the CPT probability-weighting function. Under a standard logit choice model, the likelihood contribution for observation i is:

$$L_i = \sigma(\Delta U_i)^{y_i}[1 - \sigma(\Delta U_i)]^{1-y_i},$$

with $\sigma(\cdot)$ denoting the logistic function. The sample log-likelihood is obtained using the following expression:

$$\ell(\alpha, \lambda, \gamma) = \sum_i \ln\, L_i.$$

MLE proceeds by numerically maximizing ℓ subject to the CPT constraints: $0 < \alpha < 1, \lambda > 1, 0 < \gamma < 1$. This yields parameter estimates governing diminishing sensitivity (α), loss aversion (λ), and probability distortion (γ).

Mixture Model Estimation for Behavioral Heterogeneity

Empirical evidence across industries strongly suggests that human behaviors differ systematically in their CPT parameters. To capture this heterogeneity, we suggest to adopt a finite mixture specification with K behavioral classes. Each class m has parameter vector:

$$\theta_m = (\alpha_m, \lambda_m, \gamma_m),$$

and population share π_m. The posterior probability that traveler i belongs to class m is:

$$\Pr(\text{type} = m \mid \text{data}) = \frac{\pi_m\, \sigma(\Delta U_i(\theta_m))}{\sum_{j=1}^{K} \pi_j\, \sigma(\Delta U_i(\theta_j))}.$$

The Expectation-Maximization (EM) algorithm alternates between:

- E-step: computing class responsibilities
- M-step: updating parameters $\theta_k$and mixing proportions π_k

In practice, a small number of behavioral groups is usually sufficient to capture observed variation in ancillary purchase behavior, consistent with findings in insurance and discrete-choice applications

Identification and Regularization

Estimating CPT parameters from ancillary purchase data presents identification challenges, particularly when purchase rates are low or when variation in prices and disruption probabilities is limited. In such settings, parameters governing loss aversion and probability weighting may be weakly identified or exhibit unstable estimates.

To ensure economically meaningful and numerically stable estimation, we impose standard behavioral constraints on CPT parameters:

$$0 < \alpha_m < 1, \lambda_m > 1, 0 < \gamma_m < 1, \forall m$$

These constraints enforce diminishing sensitivity, loss aversion, and nonlinear probability weighting, respectively.

Regularization is introduced to stabilize estimation in the presence of noisy probability inputs and collinearity between model components. Parameters governing probability weighting are weakly regularized toward empirically supported ranges using ridge penalties. Loss-aversion parameters are constrained to prevent implausibly large values that may arise from sparse purchase behavior.

In addition, informative priors derived from the behavioral and insurance-economics literature may be incorporated in a Bayesian or penalized-likelihood framework. These priors serve to improve convergence and interpretability without imposing restrictive structure on the model. Together, these identification and regularization strategies ensure that estimated CPT parameters are both behaviorally plausible and suitable for use in operational pricing systems.

Calibration of Mental Accounting and Credit Discounts

Travel-credit protection products require estimating mental-accounting parameters that govern how travelers value non-cash compensation relative to cash refunds. We introduce two distinct parameters to capture these effects:

- $\eta \in (0,1)$: the psychological discount applied to travel credits relative to cash at the time of evaluation
- $\delta \in (0,1)$: the devaluation or decay rate associated with credit usability, reflecting expiration, restrictions, or redemption friction

These parameters can be identified using controlled A/B experiments that vary key dimensions of refund design, including:

- refund form (cash versus credit),
- credit percentage relative to fare,
- conversion and usage restrictions.

By comparing purchase propensities across experimental conditions while holding actuarial value constant, the estimation framework will isolate travelers inferred valuation of non-cash refunds. The estimated parameters are subsequently incorporated into the CPT valuation by adjusting payoff magnitudes prior to computing value functions and decision weights.

Validation Using Out-of-Sample Experiments

Future empirical applications of the proposed CPT-based pricing framework should evaluate model performance using out-of-sample validation and controlled field experiments. Estimated CPT parameters can be applied to holdout samples not used in calibration, and predicted purchase probabilities compared against observed ancillary purchase behavior to assess predictive accuracy and calibration.

In addition, controlled A/B experiments provide a natural mechanism for evaluating pricing and revenue implications. Such experiments may vary ancillary prices, refund structures, or framing of T&C products while holding operational conditions fixed. Comparing outcomes under CPT-based pricing with those generated by heuristic or expected-value pricing rules would allow researchers to quantify revenue lift, demand sensitivity, and robustness to changes in disruption risk.

Validation should also examine stability across markets, seasons, and operational regimes, particularly during periods of elevated disruption. Consistent out-of-sample performance and stable behavioral parameter estimates would provide evidence that the CPT framework generalizes beyond the calibration sample and is suitable for deployment in airline retail systems.

SIMULATION FRAMEWORK

The purpose of the simulation framework is to translate individual Prospect-Theoretic purchase behavior into market-level demand and revenue outcomes. While the CPT model specifies how a single traveler evaluates the ancillary, pricing decisions require understanding how *aggregate demand* changes with price. Because CPT-based purchase probabilities are nonlinear and cannot be inverted analytically, simulation provides the mechanism for constructing the full revenue curve and identifying the revenue-maximizing price.

The framework described below generates a synthetic population of travelers, computes their CPT-based purchase probabilities at different price points, aggregates demand, and evaluates expected revenue across a grid of candidate prices.

Synthetic Traveler Population

A synthetic population of travelers is generated to represent the demand base for the ancillary. Each traveler is assigned:

- a disruption probability p_i,
- a benefit value $B_i$reflecting the monetary value of protection if an event occurs,
- and shared behavioral parameters $(\alpha, \lambda, \gamma)$from the two-branch CPT model.

Disruption probabilities and benefit values are drawn from empirical distributions or stylized assumptions reflecting realistic itinerary variation. Because behavioral parameters are held constant across all travelers, heterogeneity in purchase behavior arises solely from differences in $p_i$and B_i.

Two-Branch CPT Valuation

Each traveler evaluates the ancillary under the two-branch CPT formulation:

$$U_{\text{buy},i}(P) = w(p_i)\, B_i^{\alpha} - \lambda\, w(1 - p_i)\, P^{\alpha},$$

where:

- the first term reflects the perceived value if the event occurs,
- the second term reflects the perceived loss of paying for unused protection when the event does not occur.

The utility of not purchasing is normalized to zero. This formulation captures the asymmetric way travelers evaluate protection products: paying for unused flexibility is felt as a real loss, while relief from an avoided penalty often carries disproportionate psychological weight.

Purchase Probability and Aggregation

Given the utility difference:

$$\Delta U_i(P) = U_{\text{buy},i}(P),$$

traveler i's probability of purchasing at price $P$is modeled using a logit response function:

$$q_i(P) = \sigma(\Delta U_i(P)).$$

Aggregating over all travelers yields expected demand at price P:

$$Q(P) = \sum_i q_i(P)\,.$$

Aggregating individual purchase probabilities in this way produces a demand curve that approximates how the market as a whole responds to a given price level.

Revenue Computation and Optimal Price Selection

Expected revenue at price $P$is:

$$\text{Rev}(P) = P \cdot Q(P).$$

To identify the revenue-maximizing price, the simulation evaluates revenue across a grid of candidate prices. The optimal price is the maximizer of the revenue curve:

$$P^* = \arg\max_P \ \text{Rev}(P).$$

The simulation thus provides the link between psychological valuation at the traveler level and revenue optimization at the airline level.

Interpretation of Simulation Outputs

The outputs of the simulation describe how CPT-driven preferences translate into:

- take-rate behavior across prices,
- the shape of the demand and revenue curves,
- sensitivity of purchase behavior to changes in event probability and benefit level,
- and ultimately the optimal ancillary price.

Because the simulation isolates the behavioral channel, it clarifies how loss aversion, diminishing sensitivity, and probability weighting jointly determine the price that maximizes expected revenue.

MANAGERIAL IMPLICATIONS AND DISCUSSION

This section synthesizes the conceptual, empirical, and modeling insights developed in the paper into practical guidance for airline pricing teams, ancillary product managers, and retail-system architects.

Implications for Pricing Strategy

Prospect Theory highlights that travelers tend to overweight small probabilities and exhibit strong loss aversion when facing the possibility of trip disruption. These behavioral features imply that many travelers place a higher perceived value on protection products than rational EV models would suggest.

Calibrated CPT parameters allow pricing teams to map behavioral demand curves more accurately and to identify price points that reflect customers' psychological valuations

rather than purely actuarial ones. This supports more informed pricing decisions and reduces reliance on heuristics such as fixed markups, static discounts, or competitor matching.

Implications for Product Design

Different T&C structures—such as refund ladders, partial protections, or travel-credit offers—interact with behavioral components in distinct ways. The curvature of the CPT value function implies diminishing perceived value as benefit levels increase: for example, the perceived improvement from a 20% to 40% refund is typically larger than from 60% to 80%.

Awareness of these nonlinearities helps product designers choose refund levels and coverage tiers that better reflect how travelers perceive incremental value, rather than relying on evenly spaced or historically inherited benefit structures. Instead of linear benefit steps, behaviorally informed product design can produce more appealing and more efficient ancillary offerings.

Menu Optimization and Product Positioning

When several protection products are offered simultaneously, travelers evaluate them relative to each other as well as individually. Behavioral choice models help identify when certain products are unintentionally dominated, too closely spaced, or positioned in ways that distort choice.

A CPT-consistent menu structure allows airlines to create coherent product lineups that avoid cannibalization, maintain clear hierarchy, and support differentiated value propositions. By framing products in behaviorally intuitive ways, airlines can help customers navigate choices more easily while improving overall revenue performance.

Integration into Revenue Management and Retail Systems

Deploying CPT-based pricing in production environments requires modular integration with existing RM and retail architectures. Practical implementation strategies include:

- precomputing utility curves or lookup tables for various contexts,
- dynamically interpreting reference points such as fare or itinerary value,
- caching behavioral transformations to reduce computational load,
- embedding CPT-based prices or price adjustments into retail and offer-generation pipelines.

With appropriate engineering techniques—vectorization, caching, batching—CPT-derived prices can be computed with millisecond-level latency, enabling large-scale deployment across high-volume shopping environments.

Strategic Implications for Airlines

Adopting behavioral pricing frameworks has broader strategic implications. Because classical expected-value pricing often underestimates willingness to pay, it may leave ancillary revenue unrealized and limit the ability to differentiate products. A CPT-based approach:

- enhances pricing precision,
- improves demand forecasting,
- reduces mispricing exposure under shifting operational conditions,
- and offers a stable, principled foundation for long-term ancillary strategy.

Beyond technical accuracy, behavioral pricing represents a shift toward more psychologically aligned product design, positioning airlines to better meet traveler expectations while strengthening ancillary monetization.

CONCLUSION

This study develops the first end-to-end Prospect-Theoretic framework for pricing airline Terms & Conditions ancillaries, integrating behavioral foundations, structural modeling, empirical calibration, and simulation-based revenue analysis into a single coherent system. The framework demonstrates that traveler decisions around refundability, change protection, and cancellation-for-credit cannot be adequately captured by classical expected-value or heuristic pricing rules. Instead, they are shaped by systematic behavioral forces—loss aversion, diminishing sensitivity, nonlinear probability weighting, and ambiguity perceptions—that fundamentally alter willingness to pay for protection products.

By formalizing these behavioral mechanisms, deriving closed-form CPT pricing expressions for single-event and multi-event prospects, and proposing a full empirical estimation strategy grounded in real airline data, the paper establishes a scientifically rigorous foundation for behavioral ancillary pricing. The simulation engine further translates individual-level CPT behavior into market-level demand and revenue curves, enabling airlines to identify revenue-maximizing price points and evaluate alternative ancillary designs under realistic traveler responses.

Beyond methodological innovation, the framework offers clear managerial implications. CPT-based pricing supports more accurate demand forecasting, reduces mispricing risk, and enables the design of product menus that align with how travelers perceive value—not merely how airlines measure cost. When embedded into retail and revenue-management systems, CPT provides a scalable and operationally feasible approach to behavioral pricing across fare brands, refundability tiers, and protection bundles.

Overall, the framework illustrates how behavioral pricing can strengthen airline ancillary strategy by grounding price setting in empirically observed traveler behavior. While the model offers a structured path forward, further work is needed to validate its performance across markets, refine probability inputs, and examine how travelers respond to dynamic or personalized pricing contexts. By grounding T&C pricing in empirically validated behavioral economics, airlines can move beyond heuristic practices toward a principled, customer-aligned, and revenue-optimal approach to retailing flexibility products.

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- Clinical trial number: not applicable.

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