

Behavioral Factors in the Newsvendor Problem:  
A Numerical Analysis

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## **Abstract**

The newsvendor model addresses a single-period framework for determining the optimal order quantity in advance. Introducing risk aversion makes the model more realistic by capturing the cautious behavior of a risk-sensitive newsvendor compared to a risk-neutral one. However, this can lead to ambiguous outcomes in comparative statics, but is resolved by switching to a loss aversion approach. Returning to the risk-averse model and incorporating environmental consciousness further reduces order quantities, as the newsvendor seeks to minimize waste. Using different beta distribution shapes, the model simulates realistic demand scenarios, demonstrating that the risk-averse newsvendor consistently orders fewer units than the risk-neutral newsvendor and highlighting the preferred demand scenarios for each type.

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# 1 Literature Review

Imagine a newsboy standing on a busy street corner, facing a daily dilemma: how many newspapers should he buy to meet the day's demand? Order too many, and he's left with unsold copies that can only be salvaged at a loss. Order too few, and he risks missing sales opportunities, leading to lower revenue. This classic 'newsboy' scenario gave rise to the newsvendor problem, a foundational model in inventory theory designed to optimize order quantities under uncertain demand. Initially developed for this simple scenario, the model has since become a versatile tool applied across industries from logistics to technologies managing fluctuating demand and optimizing critical resources.

To explore the complexities of this model further, this thesis addresses the research question: To explore the complexities of this model further, this thesis addresses the research question: "How do behavioral factors - such as risk aversion, loss aversion, and environmental consciousness - influence ordering decisions in the newsvendor problem?"

Initially, the model assumed risk neutrality, focusing solely on maximizing expected profit. Gradually, risk aversion was incorporated, and one of the first comprehensive studies on the risk-averse newsvendor was conducted by Eeckhoudt et al. (1995), which focused on maximizing expected utility under different risk-utility functions. This thesis builds upon this foundational work to carry out further calculations and analyses, similar as in Katariya et al. (2014) and Mohan et al. (2023).

However, subsequent studies have questioned this approach, pointing out certain limitations. Notably, Rabin has conducted extensive research on this topic, Rabin (2000a) and Rabin (2000b) suggest that alternative factors, such as loss aversion - a key component of prospect theory as introduced by Kahneman and Tversky (1979) - may capture real-world decision-making behavior more accurately.

Furthermore, Wang et al. (2009) argue that relying solely on expected utility can lead to counterintuitive outcomes which was explicitly mentioned

in Herweg (2013): *"Modeling the newsgirl's preferences based on expected utility theory (EUT), however, often leads to implausible comparative statics, e.g., the order quantity decreases if the retail price increases."* This effect, alongside other factors, will be examined in the comparative statics section.

In their work, Sharma and Nandi (2018) emphasize the significance of human behavior in decision-making, categorizing it into three main dimensions: individual decision biases (including risk aversion, loss aversion, and waste aversion); social preferences (such as fairness or inequity aversion), where individuals consider the welfare of others in their environment, often leading to a decrease in personal utility; and cultural factors, where a decision-maker's knowledge and skills are shaped by the national and regional cultural context of the market. As an example, Wu and Niederhoff (2014) examine the impact of fairness concerns in the newsvendor model and Feng et al. (2011) as well as Cui et al. (2013) explore cultural influences on the newsvendor problem and reveal differences in decision-making approaches between American and Chinese decision-makers.

This thesis focuses specifically on the dimension of individual decision bias, building on the comprehensive research by Herweg (2013) on loss aversion. Wang and Webster (2009) conducts a similar analysis, considering a fixed endogenous point, while Herweg examines a reference point defined by the newsvendor's rational expectations. Herweg applies the reference-dependent utility model from Kőszegi and Rabin (2007), where outcomes are perceived as gains or losses relative to recent expectations, integrating both "consumption utility" and "gain-loss utility". Schweitzer and Cachon (2000) is among the first who investigated the effect of loss aversion to decision-makers through experimental studies. Although loss aversion provides a more accurate representation of real-world behavior, it has its limitations: Novemsky and Kahneman (2005) explores the boundaries of loss aversion, demonstrating that it is also influenced by an agent's intentions.

Beyond risk and loss aversion, numerous other behavioral biases have been extensively studied in the realm of human decision-making. Bell (1982)

investigates how regret influences decision-making, while Bolton and Katok (2004) analyze whether experience and feedback contribute to improved decision-making in the newsvendor model. Su (2008) explores the concept of bounded rationality in newsvendor decisions, suggesting that this limitation leads to errors in ordering decisions. Similarly, Ren et al. (2017) examine the impact of overconfidence on the newsvendor's behavior.

Expanding upon Arkes (1996)'s experimental research on waste, aligning with the growing emphasis on sustainability in recent years, the newsvendor model is extended to incorporate environmental consciousness, examining how heightened environmental awareness impacts the newsvendor's dual objectives: maximizing expected utility while striving to reduce waste.

The newsvendor problem typically assumes that demand is known and follows a normal or uniform distribution, an assumption questioned by Ren et al. (2017) who suggests that "*(...) studies of newsvendor decision biases under nonuniform demand would be a good starting point.*". Benzion et al. (2010) examines the impact of known versus unknown demand distributions on the newsvendor's decision-making, finding that this factor is less influential than loss aversion in affecting order quantities. Similarly, O'Neil et al. (2015) develops an algorithm using machine learning to simulate scenarios with unknown demand, requiring the newsvendor to adapt dynamically to demand shocks.

Due to the limited research on the impact of beta distributions on the newsvendor model (Gürler et al. (2008) and Daskin et al. (2024)), this thesis addresses this gap by transforming the two-state demand model into a beta distribution framework. This approach allows for a more detailed investigation into how different demand scenarios affect the ordering behavior of risk-neutral and risk-averse newsvendors.

## 2 Newsvendor Problem

### 2.1 The Basic Model

Building on the work of Eeckhoudt et al. (1995), the parameters and functions defined in their study are adopted. In the simple newsvendor problem, the newsvendor faces an uncertain demand,  $\theta$ , with a known probability distribution. Further defined are his initial wealth  $z_0$ , retail price  $p$ , purchase price  $c$  and salvage value  $v$  which represents the amount recoverable for any unsold units. Additionally, there is an option to purchase additional newspapers at a higher price  $\hat{c}$  during the selling period.  $0 \leq v < c < \hat{c} \leq p$  is assumed to ensure that the newsvendor can operate a profitable business.

The risk-neutral newsvendor must determine in advance the order quantity  $\alpha$ , that maximizes expected profit, as defined by the following payoff function:

$$Z(\theta, \alpha) = \begin{cases} Z_-(\theta, \alpha) = z_0 + (p - v)\theta - (c - v)\alpha & \text{if } \theta \leq \alpha, \\ Z_+(\theta, \alpha) = z_0 + (p - \hat{c})\theta + (\hat{c} - c)\alpha & \text{otherwise.} \end{cases} \quad (1)$$

Define the scenario in which the newsvendor refrains from purchasing additional units with  $c = 20$  and  $\hat{c} = p = 28$ . Moreover, set  $z_0 = v = 0$ , implying that the newsvendor has no initial wealth and can't resell any unsold units.

From Equation 1, Eeckhoudt et al. (1995) derives the critical fractile to calculate the optimal order quantity (OOQ) for the risk-neutral newsvendor:

$$F(\alpha^*) = \frac{\hat{c} - c}{\hat{c} - v} \quad (2)$$

Substitute the defined values into Equation 2 and solve under a normal distribution with a mean of 75 and a standard deviation of 25, yields an OOQ for the newsvendor of 61 units. To maintain the flow of the text, these and additional calculations are only included in the appendix.

## 2.2 Risk Preferences

Assuming risk neutrality for the newsvendor greatly simplifies the model and calculations. However, real-world decision-making and human behavior are far more complex. By focusing solely on expected profit, the risk-neutral newsvendor overlooks key aspects, such as uncertainty and variability in outcomes and potential losses. To address these limitations and enhance the model's predictive accuracy, risk aversion will be taken into account.

Incorporating risk aversion into decision-making models reflects a fundamental human preference for security. Risk-averse people value the certainty of lower returns over higher, riskier gains to avoid potential losses. For a risk-averse newsvendor, this preference significantly influences inventory decisions, leading to smaller advance orders as risk aversion increases, as demonstrated in Eeckhoudt et al. (1995) and further evidenced in our analysis.

For a risk-averse newsvendor, the objective shifts from maximizing expected profit to maximizing expected utility, a concept that quantifies the satisfaction or value derived from different outcomes. The utility function reflects the newsvendor's sensitivity to risk, enabling the evaluation of expected utility across various possible outcomes and aligning the optimal order quantity with the individual's level of risk aversion. To explore this further, two specific utility functions that model different forms of risk preferences are examined.

**Constant Absolute Risk Aversion (CARA):** The CARA utility function presumes a constant level of risk aversion across all levels of profit or wealth and is defined as:

$$U(Z) = -\exp(-rZ), \tag{3}$$

where  $Z$  represents payoff and  $r$  indicates the degree of risk aversion. In this context  $r = 0$  corresponds to risk neutrality, while  $r < 0$  would represent risk-seeking behavior. Since the CARA function is specifically constructed to model risk aversion,  $r$  is restricted to values greater than zero.

**Decreasing Absolute Risk Aversion (DARA) and Hyperbolic Absolute Risk Aversion (HARA):** In contrast to CARA, the DARA utility function accounts for the tendency of individuals to become less risk-averse as wealth or payoff increases. This behavior is commonly observed in the real world, where wealthier individuals or groups may take on riskier actions, as they are better equipped to handle potential losses. However, the DARA function, as defined in Equation 4, struggles with negative payoffs, limiting its application in situations where losses are significant.

$$U(Z) = \frac{Z^{1-\gamma}}{1-\gamma} \quad (4)$$

To address this, the DARA function is transformed into a HARA function with a constant shift  $b$ , allowing for both positive and negative values while retaining the properties of DARA:

$$U(Z) = \frac{(Z+b)^{1-\gamma}}{1-\gamma} \quad (5)$$

As defined earlier,  $Z$  represents profit, and  $\gamma$  is the risk aversion parameter, constrained to  $\gamma > 0$  for the same reasons.

### 2.3 Applying Risk Aversion

For simplicity, a two-state demand model is applied where  $\theta$  is 0 or 100, with probabilities of 25% and 75%. Using the same parameters as the risk-neutral newsvendor and Equations 3 & 5, the optimal order quantities are derived for CARA and HARA, shown in Table 1.

There are no major differences between the CARA and HARA results, as both utility functions describe a risk-averse newsvendor similarly. This similarity arises because initial wealth is not yet included, which would impact the HARA model specifically.

The results indicate that as the degree of risk aversion increases, the optimal order quantity decreases in both models. Due to the concavity of the utility functions, the reduction in optimal order quantity is more pronounced with

small increments of  $r = 0.00001$  near zero and becomes less significant as  $r$  increases.

In contrast to the risk-neutral newsvendor, who consistently orders a positive quantity, the risk-averse newsvendor adjusts the order quantity according to his level of risk aversion.<sup>1</sup> At a certain level, the risk aversion becomes so strong that the newsvendor sacrifices any potential gains and orders zero units to completely avoid possible losses.

Table 1.a CARA		Table 1.b HARA	
Risk Aversion $r$	Optimal Order	Risk Aversion $\gamma$	Optimal Order
0.00001	100	0.025	100
0.00007	93	0.05	96
0.00008	81	0.10	79
0.00009	72	0.15	63
0.00010	65	0.20	52
0.00015	43	0.30	37
0.0002	33	0.40	29
0.0003	22	0.50	24
0.0004	16	1.00	13
0.0005	13	2.00	6
0.001	7	5.00	3
0.005	1	10.00	1
0.02	0	30.00	0

Table 1: OoQ across different levels of risk aversion for the CARA model (Table 1.a) and the HARA model (Table 1.b)

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<sup>1</sup>Unlike the two-state demand model used in the risk aversion analysis, a normal distribution is applied to illustrate the typical behavior of a risk-neutral newsvendor, offering a general overview rather than a direct comparison with risk-averse outcomes.

### 3 Comparative Statics

Since the comparative statics results in Eeckhoudt et al. (1995) were derived using heuristic methods, selected parameter changes are re-examined here through numerical analysis to identify any potential inconsistencies.

#### 3.1 Initial Wealth $z_0$

Consider the newsvendor starting with an initial wealth  $z_0$ . Neither the critical fractile of the risk-neutral newsvendor nor the risk-averse newsvendor under the CARA utility function depends on  $z_0$ ; therefore, they will not be examined in detail.<sup>2</sup> By contrast, the HARA utility function is influenced by changes in wealth in two ways: first, through the payoff  $Z$ , which directly responds to variations in wealth, and second, through the introduced shift  $b$ , which serves a function similar to  $z_0$ .

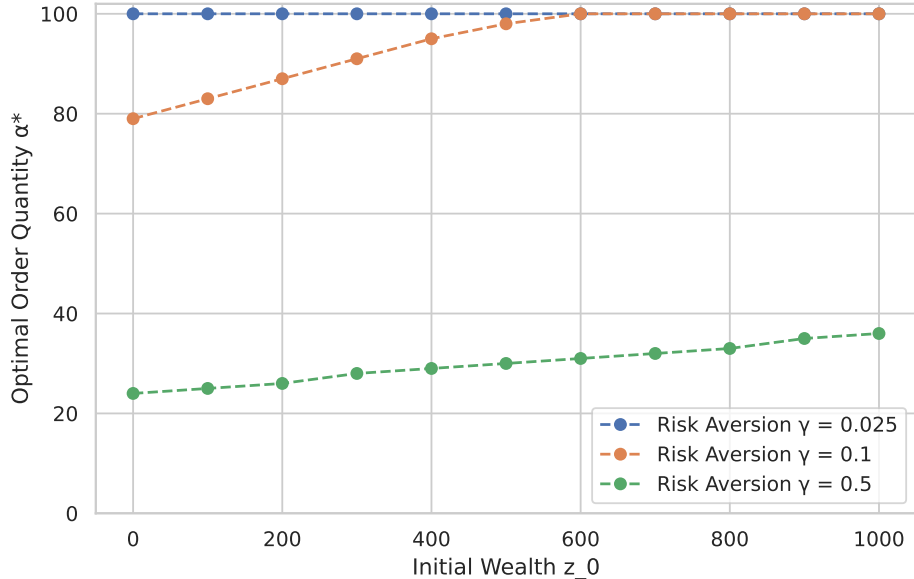


Figure 1: Effect of initial wealth  $z_0$  on OQ  $\alpha^*$  under HARA utility function for different levels of risk aversion

<sup>2</sup>The code provided in the appendix demonstrates that as wealth increases, the CARA agent's ex-ante order quantity remains unchanged, confirming its independence from initial wealth.

Figure 1 shows the OOQ of a risk-averse newsvendor under HARA with  $b = 2001$ .<sup>3</sup> Increases in initial wealth  $z_0$  lead to a linear rise in the OOQ, reflecting the characteristics of HARA utility functions with decreasing absolute risk aversion. As wealth grows, the newsvendor's sensitivity to risk diminishes, gradually approaching behavior similar to a risk-neutral stance. Additionally, the shift parameter  $b$  significantly influences the utility function, resulting in a linear adjustment of the OOQ. While this relationship is linear, the economic interpretation remains consistent, highlighting the reduced impact of risk aversion at higher wealth levels.

The figures also illustrate the changes in OOQ for three different levels of risk aversion  $\gamma$ . The same intuition applies here: the more risk-averse the newsvendor is, the less he will order in advance. At a certain level of wealth, however, each risk aversion level  $\gamma$  converges to the maximum possible demand, as the newsvendor's wealth becomes sufficiently high. Since ordering beyond the maximum demand generates no benefit in this model, for sufficiently high  $z_0$ , the OOQ will ultimately converge to the maximum demand of 100. Meanwhile, for small values of  $\gamma$  - e.g. under 1, the initial wealth  $z_0$  becomes insignificant, as the effect of  $b$  is already so pronounced that it renders  $z_0$  irrelevant. Consequently, the newsvendor orders up to the maximum demand.

### 3.2 Newspaper Price $p$

The impact of changes in newspaper price  $p$  on the OOQ for risk-averse agents under CARA is illustrated in Figure 2. Initially, there is a rapid increase in OOQ, as the newsvendor begins to make a profit once the newspaper price exceeds the purchase price ( $p > c = 20$ ). For agents with very low risk aversion, the OOQ jumps immediately to the maximum demand. However, at a certain higher  $p$  value, the OOQ begins to decrease, even though a higher  $p$  should imply a greater potential payoff, which supports Wang et al. (2009)'s criticism.

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<sup>3</sup>In this setup the most negative payoff is 2000, 1 is added to ensure that the equations apply to all cases.

Moderately risk-averse agents follow a similar trend but with a slower initial increase, and the decrease in OOQ begins at a lower  $p$  level. Highly risk-averse agents, on the other hand, are so cautious that they never place any orders.

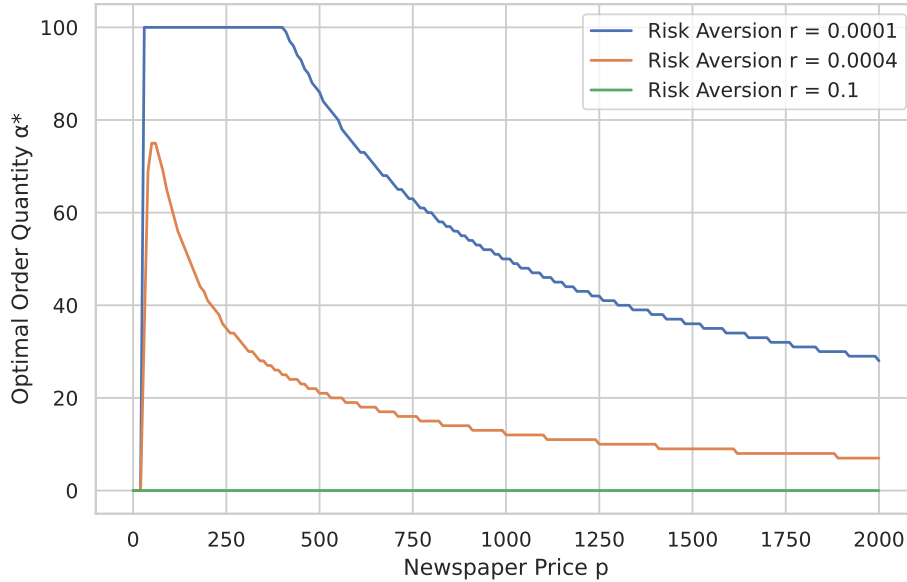


Figure 2: Effect of newspaper price  $p$  on OOQ  $\alpha^*$  under CARA utility function for different levels of risk aversion

In contrast, Figure 3 demonstrates the effect of changes in newspaper price on OOQ under the HARA utility function, which behaves almost identically to CARA. Highly risk-averse agents refrain from ordering, while OOQ for average risk-averse agents initially increases with  $p$  before declining beyond a certain threshold. Compared to CARA, HARA shows a more tempered response to changes in  $p$ , due to the influence of the  $b$ , which helps to absorb losses. For  $\gamma = 0.1$ , the risk-averse news vendor nearly rises to high demand levels quickly, then gradually converges to the maximum demand. The news vendor on the blue curve remains at this level, which aligns with the expected behavior that as the newspaper price  $p$  continues to increase, he will order as many units as possible because of the high ratio from newspaper price  $p$  and purchase price  $c$ .

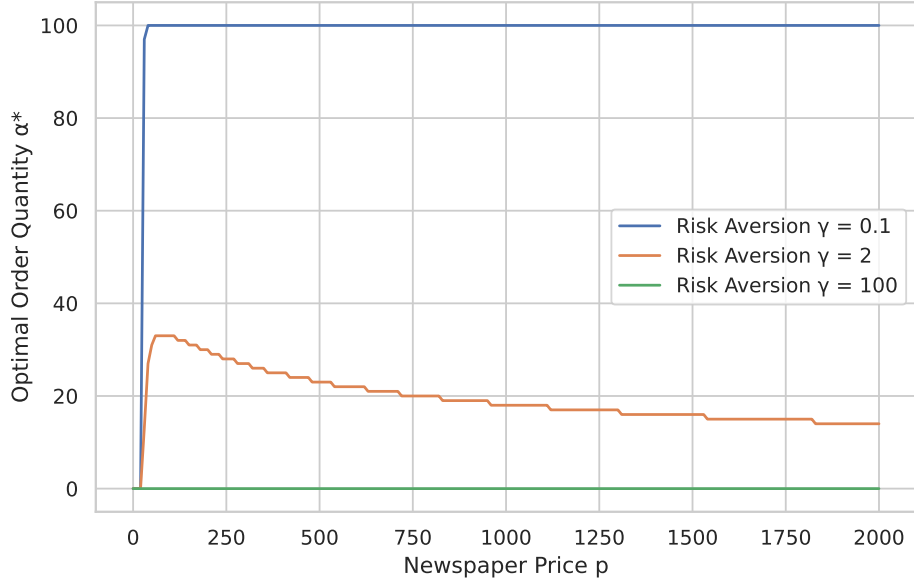


Figure 3: Effect of newspaper price  $p$  on OOQ  $\alpha^*$  under HARA utility function for different levels of risk aversion

In some cases, under both CARA and HARA, the newsvendor behaves unexpectedly, emphasize the limitations of expected utility in accurately capturing real-world behavior.

### 3.3 Salvage Value $v$

In this section, the model is extended to allow the newsvendor to sell any unsold units to a third party at the salvage value  $v$ .

Figure 4 shows the effect of changes in  $v$  on the critical fractile for the risk-neutral agent. For a risk-neutral agent, the OOQ increases as  $v$  rises, as this allows partial recovery of potential losses. Since the equation is not defined for  $v = c = 20$ , the limit is examined as  $v$  approaches 20. As  $v$  converges toward  $c$ , potential losses decrease increasingly to negligible amounts, prompting the agent to cover as much demand as possible. To illustrate, a value of 133 covers 99% of the defined normal distribution. When  $v = 19.95$ , the OOQ already reaches 138 units, indicating that the agent would cover nearly the entire distribution as  $v$  approaches  $c$ .

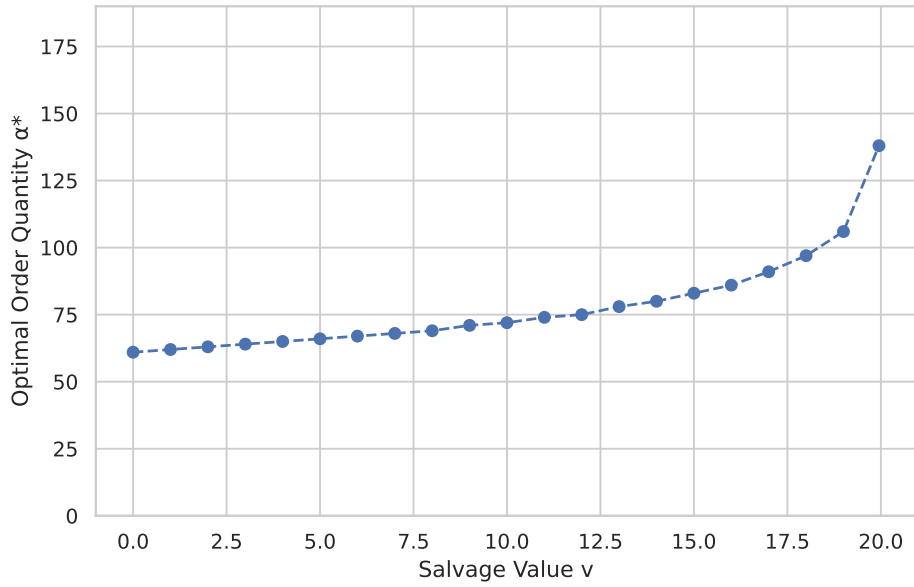


Figure 4: Effect of salvage value  $v$  on OOQ  $\alpha^*$  of a risk-neutral newsvendor

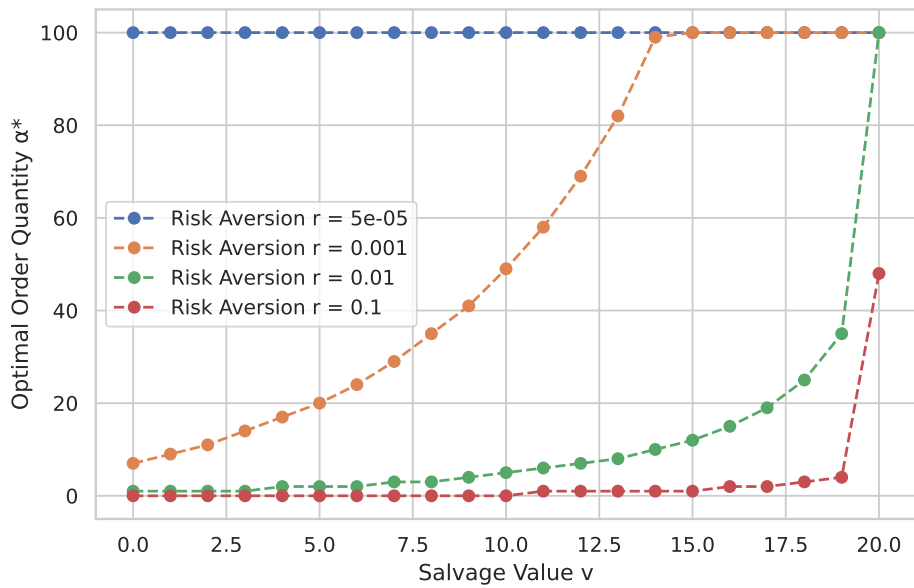


Figure 5: Effect of salvage value  $v$  on OOQ  $\alpha^*$  under CARA utility function for different levels of risk aversion

Figure 5 illustrates the behavior of a risk-averse newsvendor under the CARA utility function, showing that the OOQ increases with salvage value  $v$ . The higher salvage value provides a greater return on unsold goods, thereby

reducing the newsvendor's potential losses. For very low risk aversion (blue curve), salvage value becomes irrelevant, and the newsvendor consistently orders the maximum demand. At moderate  $r$  levels (orange curve), the newsvendor reaches maximum demand even before  $v = c$ , as partial salvage value sufficiently offsets potential losses. More risk-averse agents (green curve) only reach maximum demand when  $v = c$  ensuring no losses, while the most risk-averse (red curve) refrain from ordering the maximum, even without risk of loss. This scenario further highlights the limitations of expected utility, as it is typically assumed that when  $v = c$ , the newsvendor would order the maximum quantity: in the low-demand state, the salvage value enables recovery of any losses, and in the high-demand state, it allows for maximum profit.

## 4 Behavioral Factors Beyond Risk Aversion

### 4.1 Loss Aversion

Loss aversion describes the tendency for individuals to weigh losses more heavily than gains of the same magnitude: as an example, for a value function  $v(\cdot)$  holds  $v(100) < |v(-100)|$ .<sup>4</sup> A classic example illustrating loss aversion is the experiment by Kahneman et al. (1990) on the endowment effect: people tend to assign a higher selling price to a mug they own compared to the price they would be willing to pay to acquire it. This discrepancy aligns with loss aversion because the pain of losing the mug feels greater than the pleasure of acquiring it.

With loss aversion, the newsvendor compares his current payoff to a reference point. If the payoff falls below this reference point, it is perceived as a loss, even if the payoff remains positive. To illustrate this, the definitions of Herweg (2013) are used.<sup>5</sup> The newsvendor's utility is divided into two components: the utility derived from selling the newspapers and the gain-loss utility.

$$U = Z(\theta, \alpha) + m(R - Z(\theta, \alpha)) \quad (6)$$

where  $Z$  represents the realized payoff and  $m(\cdot)$  captures the agent's loss aversion. The gain-loss function  $m(\cdot)$  evaluates the payoff relative to the reference point  $R$ :<sup>6</sup>

$$m(z) = -\lambda[z]^+, \quad (7)$$

with  $[z]^+ = z$  for  $z > 0$  and  $[z]^+ = 0$  for  $z \leq 0$ . The parameter  $\lambda \geq 0$  measures the degree of loss aversion and when  $\lambda = 0$ , then the model is reduced to the utility function without loss aversion.

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<sup>4</sup>Barberis (2013)'s Figure 1 shows such a value function of a loss-averse individual.

<sup>5</sup>Herweg distinguishes between newsvendor problems with and without shortage costs. In this analysis, the model is evaluated without considering shortage costs.

<sup>6</sup>To distinguish it from the risk aversion parameter  $r$ ,  $R$  is used to denote the reference point.

Using the payoff function, the payoffs for the low demand state ranges from  $[-2000, 0]$  and the payoffs for the high state ranges from  $[0, 800]$ .

Define for each demand state a reference point  $R$ :

$$R_{\text{low}} = -1000 * \frac{1}{1 + \lambda} \quad (8)$$

$$R_{\text{high}} = 400 * \frac{1}{1 + \lambda} \quad (9)$$

and so, define the loss domain for all negative payoffs as  $[-2000, R_{\text{low}}]$  and for all positive payoffs the loss-domain as  $[0, R_{\text{high}}]$ . This interpretation is as follows: if a negative payoff falls within the loss domain, it is lower than expected, amplifying the perceived pain of the loss. Similarly, if a positive payoff is within the loss domain, it is less than anticipated, diminishing the perceived satisfaction of the gain. The gain-domain is defined for negative payoffs as  $[R_{\text{low}}, 0]$  and for positive payoffs as  $[R_{\text{high}}, 800]$ .

Dividing the reference point by  $\lambda$  affects the utility:  $R_{\text{high}}$  is lower and so, the positive gain domain expands, resulting in higher utility since the gain-loss function equals 0 within this range. Simultaneously, the increase in  $R_{\text{low}}$  expands the negative loss domain, resulting in more payoffs being affected by the gain-loss function. As the newsvendor becomes more loss-averse,  $m(\cdot)$  increases, causing negative utilities to outweigh positive utilities, ultimately reducing the expected utility for all ordered units  $\alpha$ . Using Equations 6 - 9, Figure 6 shows that OOQ decreases with increasing loss aversion.

In Figure 7, the effects of salvage value  $v$  on OOQ are shown for different loss aversion: The OOQ increases with the salvage value across all levels of loss aversion — low, medium, and high. However, highly loss-averse newsvendors are unaffected by the salvage value, as they already order the maximum demand regardless of its value. Highly loss-averse newsvendors show minimal response to increases in  $v$  until it approaches a value close to the purchase price  $c$ . By the point where  $v = c$ , all curves converge to the maximum demand.

Figure 8 illustrates the relationship between newspaper price  $p$  and OOQ under varying levels of loss aversion  $\lambda$ . For all values of  $\lambda$ , OOQ increases as the newspaper price  $p$  rises. For low and medium levels of loss aversion,

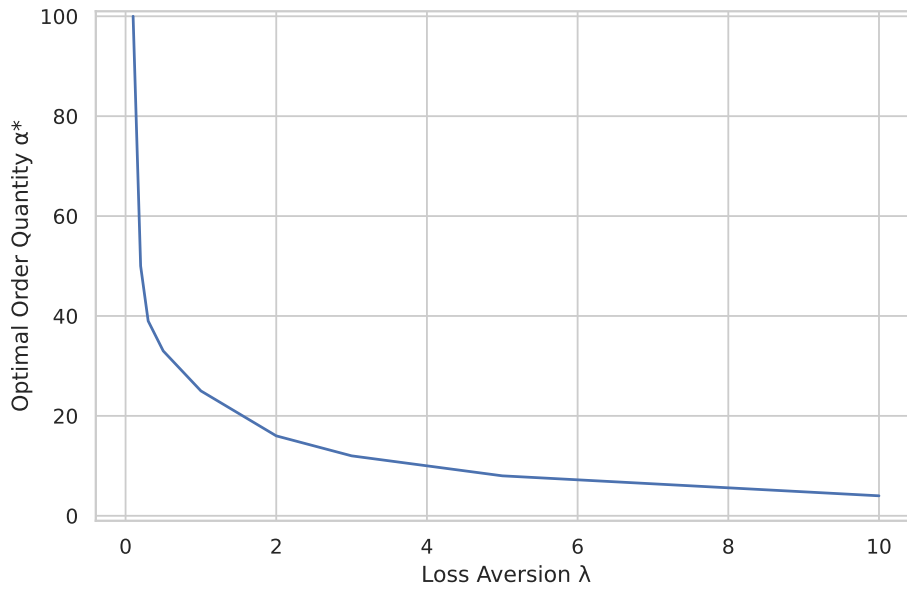


Figure 6: Effect of loss aversion on OOQ  $\alpha^*$

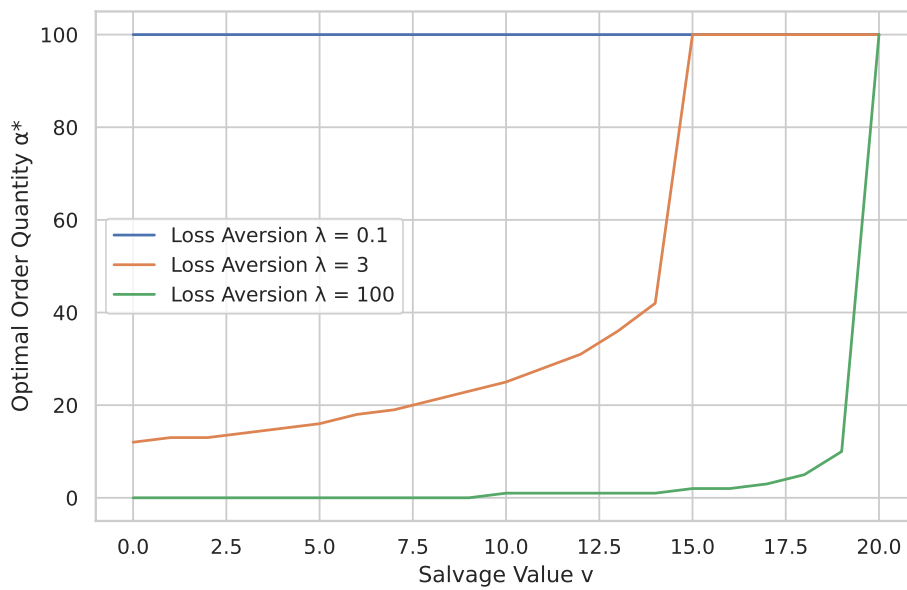


Figure 7: Effect of salvage value  $v$  on OOQ  $\alpha^*$  for different levels of loss aversion

the newsvendor's OOQ rises sharply to the maximum demand as soon as  $p = c = 20$ . Highly loss-averse newsvendors initially order no units but eventually increase their order quantity to the maximum demand as  $p$  continues to rise.

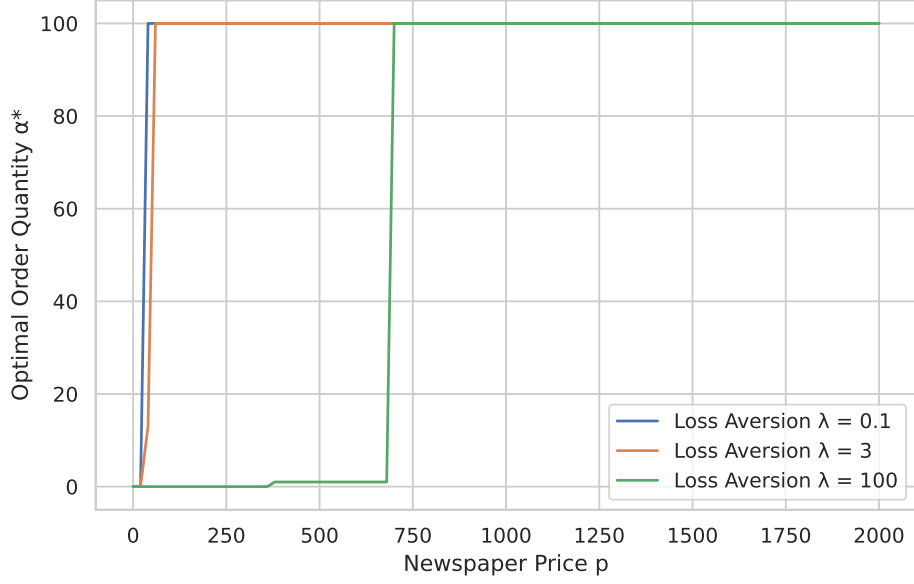


Figure 8: Effect of newspaper price  $p$  on OOO  $\alpha^*$  for different levels of loss aversion

In both figures, the loss-averse newsvendor increases his OOO as conditions improve, making it more worthwhile to order additional units. At all levels of loss aversion  $\lambda$ , the OOO does not decrease, indicating that adopting a loss aversion model effectively addresses the limitations observed when relying solely on risk aversion.

## 4.2 Environmental Consciousness

Nowadays, more and more attention is being paid to the environment. What happens to the newsvendor model if the seller behaves in such a way as to waste as little as possible? To incorporate this behavioral factor into the model, an environmental contribution is introduced in the payoff function  $Z$ , represented by  $\lambda_{\text{env}}$ , resulting in the following payoff equation:

$$Z_{\text{env}}(\theta, \alpha) = \begin{cases} Z_-(\theta, \alpha) = z_0 + (p - v)\theta - (c - v)\alpha - \lambda_{\text{env}}(\alpha - \theta)^2, & \text{if } \theta \leq \alpha, \\ Z_+(\theta, \alpha) = z_0 + (p - \hat{c})\theta + (\hat{c} - c)\alpha, & \text{otherwise.} \end{cases} \quad (10)$$

For example, this could represent the newsvendor making a contribution to a climate organization at the end of the period to alleviate his environmental concerns. The term  $\lambda_{\text{env}}(\alpha - \theta)^2$  represents a quadratic cost structure, reflecting how waste increases expenses significantly. Higher levels of overstock become increasingly costly for the newsvendor, as they conflict with his environmental consciousness.

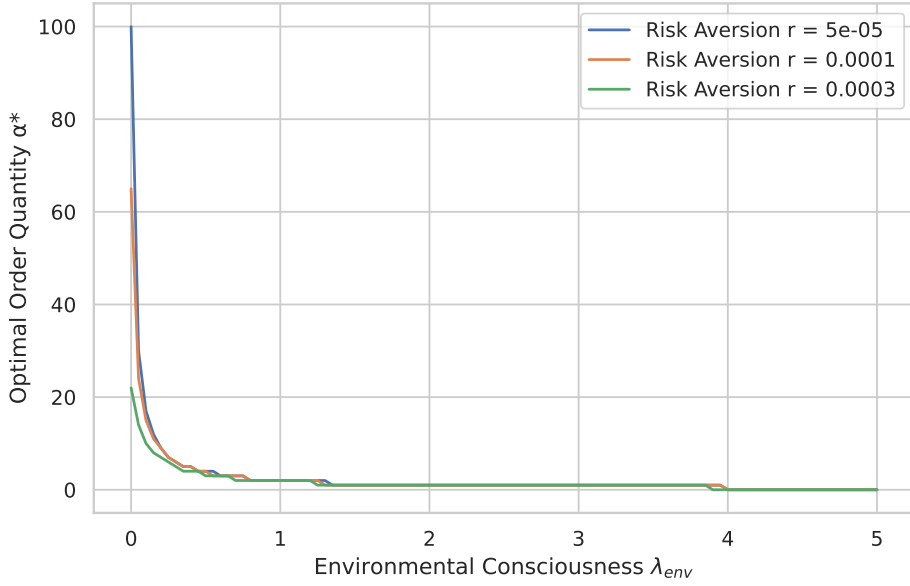


Figure 9: Effect of an environmental consciousness  $\lambda_{\text{env}}$  on OOQ  $\alpha^*$

In Figure 9, the newsvendor takes his environmental consciousness  $\lambda_{\text{env}}$  into consideration under the CARA utility function. For low values of  $\lambda_{\text{env}}$  the risk-averse newsvendor's behavior remains similar to previous scenarios. However, as  $\lambda_{\text{env}}$  increases, the newsvendor reduces his OOQ. Even at a low level of  $\lambda_{\text{env}}$ , the OOQ drops significantly for newsvendors with low risk aversion. Moderately risk-averse newsvendors start with a lower OOQ and are less impacted by environmental concerns. When  $\lambda_{\text{env}}$  reaches 0.5, the OOQ for all risk-averse agents converges to a similar level, and as it continues to rise, the newsvendor's ordering becomes minimal due to his desire to avoid waste. At  $\lambda_{\text{env}} = 4$ , his environmental consciousness influences him so strongly that he ceases ordering newspapers altogether.

## 5 Analysis under Beta Distribution

In this part, the model transitions from a two-state demand model to one where demand follows a beta distribution. Johnson and Beverlin (2013)'s paper provides an overview of the beta distribution. It's a continuous density function defined for a value  $x$  on the interval  $(0, 1)$ . For the following calculations, the x-axis has been scaled by a factor of 100 to represent demand. Additionally, it has two positive parameters  $\alpha'$ <sup>7</sup> and  $\beta$ , which control the shape of the distribution. The beta distribution is defined as:

$$\text{Beta}(\alpha, \beta) = \frac{x^{\alpha-1}(1-x)^{\beta-1}}{B(\alpha, \beta)} \quad (11)$$

where

$$B(\alpha, \beta) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha + \beta)} \quad (12)$$

and  $\Gamma$  is the gamma function.<sup>8</sup> For this thesis, it is important to note that the  $B(\alpha, \beta)$  is used to ensure the area under the distribution curve equals 1, since the density function of the beta distribution is already integrated into the programming language.<sup>9</sup>

By varying the parameters  $\alpha'$  and  $\beta$  in Equation 11, this thesis examines four distinct distribution shapes, as illustrated in the left part of Figure 10.<sup>10</sup> The bell-shaped curves resemble a normal distribution. The U-shaped distributions have demand concentrated near 0 and 100. The left- and right-skewed distributions, where demand is heavily centered either on the lower or on the higher demand spectrum.

Using different beta distributions allows real-world scenarios to be incorporated into the model. Scenario 1: A seasonal product (e.g. winter gloves), where demand is generally moderate but spikes at the beginning

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<sup>7</sup>To avoid any confusion with the previously defined ex-ante order quantity  $\alpha$ , the notation  $\alpha'$  is used here.

<sup>8</sup>"The gamma function was first introduced by the Swiss mathematician Leonhard Euler to generalize the factorial to non integer values." by Sebah and Gourdon (2002).

<sup>9</sup>For additional details, see Sebah and Gourdon (2002) for an overview of the gamma function.

<sup>10</sup>For  $\alpha' = \beta = 0$ , the distribution is uniform, but this case will not be covered in this section.

of the season and, on rare occasions, is purchased out of season. Scenario 2: Event-specific items (e.g. christmas trees), where demand is extremely high during the event but nearly zero at other times. Scenario 3: Luxury goods (e.g. a high-end watch), where demand is usually low, as these items are purchased infrequently. Scenario 4: Basic goods (e.g., groceries), where demand is consistently high due to their essential nature for everyday living.

For the calculations, the risk-averse agent is assigned a risk aversion parameter of  $r = 0.01$  under the CARA utility function, and the previously established parameter values are applied once more.

Figure 10 presents four sets of plots: On the left side, different beta distributions are illustrated for each case, while the right side displays the corresponding OOQ for each distribution. As the parameters  $\alpha$  or  $\beta$  increase (or decrease for U-shaped distributions), the curves become more pronounced. This change in parameter values is reflected on the x-axis of the plots on the right. The right side shows how the risk-averse newsvendor reacts differently compared to the risk-neutral.

As bell-shaped distributions become more concentrated around a demand of 50, the OOQ increases. For U-shaped distributions, however, the OOQ decreases, as demand tends to be either closer to 0 or 100. In the case of increasingly extreme left-skewed distributions, high demand becomes rare, leading the newsvendor to order fewer units. Conversely, as the right-skewed distribution becomes more extreme, low demand becomes unlikely, resulting in a higher OOQ for the newsvendor.

In every scenario, the risk-averse always orders less units than the risk-neutral newsvendor. For all beta distributions, the risk-averse newsvendor orders only around half as many units as the risk-neutral newsvendor when  $\alpha$  and  $\beta$  are at lower values. As these values increase, the risk-neutral newsvendor's reaction is less significant, while the risk-averse agents' OOQ approaches that of the risk-neutral. An exception occurs with very low parameters in the U-shaped case, where the risk-averse agent orders more units than the risk-neutral agent, likely due to rounding effects.

The risk-averse newsvendor has a strong aversion to U-shaped demand distributions, consistently ordering significantly fewer units than the risk-neutral newsvendor, especially when  $\alpha$  and  $\beta$  are close to 1.

In unfavorable scenarios, such as left-skewed distributions, the risk-neutral and risk-averse newsvendors react similarly, although they differ significantly in U-shaped distributions. In favorable scenarios, like right-skewed distributions, the risk-averse newsvendor orders considerably fewer units than the risk-neutral newsvendor; however, for bell-shaped distributions, their order quantities are more similar. Thus, it is challenging to clearly distinguish between favored scenarios and the effects of risk-neutrality versus risk-aversion.

Both newsvendors favor bell-shaped and right-skewed demand distributions, while they tend to avoid U-shaped and left-skewed distributions, ordering fewer units for these compared to other types. In terms of preferences, the risk-neutral newsvendor ranks the distributions as follows: *left-skewed* < *U-shaped* < *bell-shaped* < *right-skewed*. The risk-averse newsvendor, however, ranks them as *U-shaped* < *left-skewed* < *bell-shaped* < *right-skewed*. This distinction underscores the behavioral differences between the risk-averse agent and the risk-neutral newsvendor. Due to risk aversion, the risk-averse newsvendor has a strong aversion to U-shaped distributions, preferring left-skewed distributions instead. In contrast, the risk-neutral newsvendor favors U-shaped distributions over left-skewed ones, as they maximize expected profit.

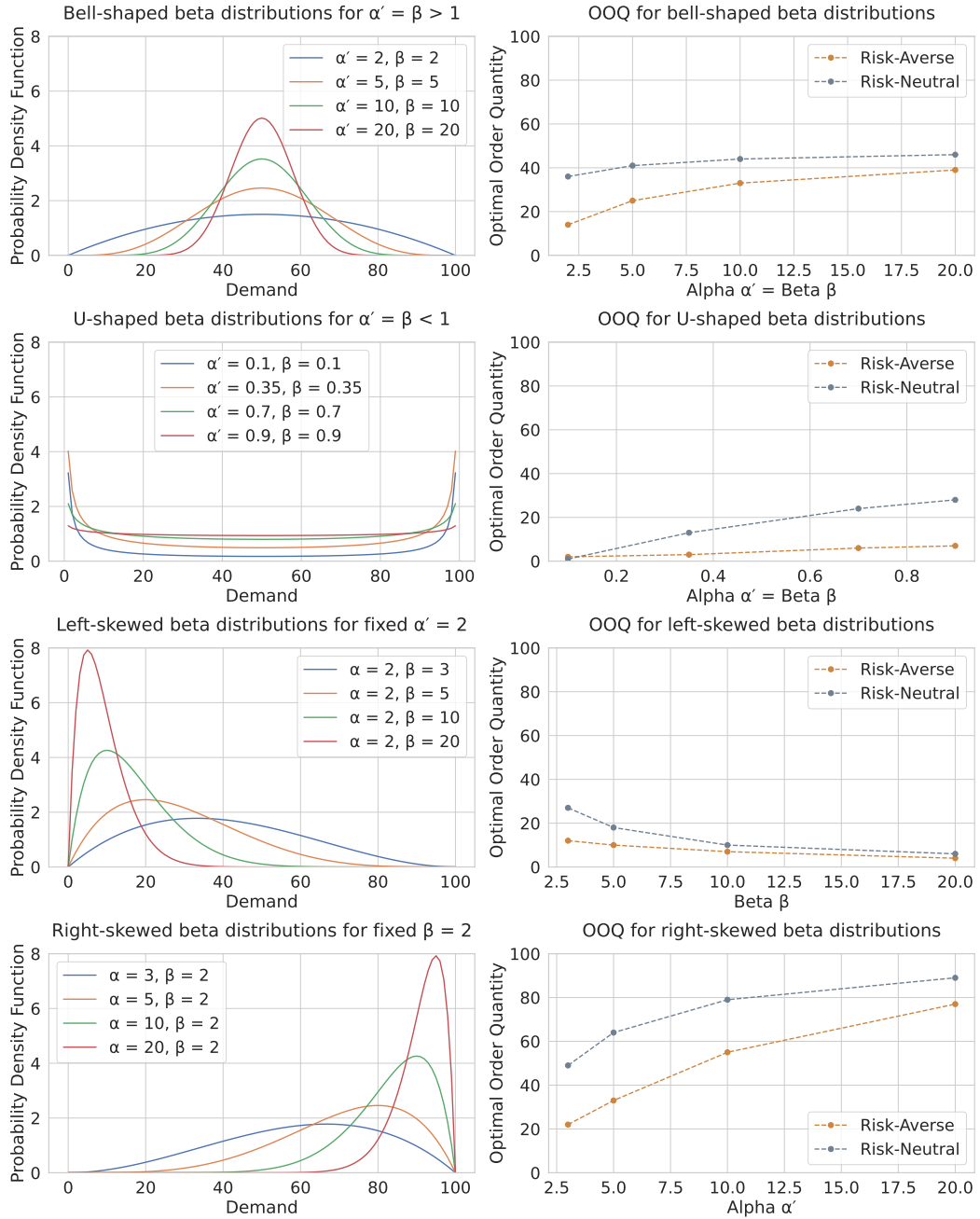


Figure 10: Overview of beta distributions and corresponding optimal order quantities for a risk-neutral and risk-averse newsvendor

## 6 Conclusion

In the second section, I established the framework of the basic newsvendor model. Introducing risk aversion made the model more realistic, as risk-averse newsvendors tend to order less in advance compared to their risk-neutral counterparts, who always order a fixed amount.

In the third chapter, I conducted comparative statics to analyze how the risk-averse newsvendor responds to changes in model parameters. During this analysis, I addressed criticisms of relying solely on expected utility, confirming the limitations of risk aversion when adjusting factors such as the newspaper price  $p$  or salvage value  $v$ .

The subsequent chapter adapted the model from a risk-averse to a loss-averse newsvendor. In this setup, the comparative statics analysis revealed that shifting to loss aversion resolves the ambiguities observed with risk aversion.

Given that the newsvendor model was developed many years ago, I introduced a modern scenario: a climate-conscious newsvendor aiming to minimize waste. As environmental awareness increases, the newsvendor orders fewer units in advance. Future research could explore how this impacts equilibrium if consumer behavior is also considered. Would the optimal order quantity remain low, or would the newsvendor increase it as product scarcity raises consumer willingness to pay more? Additionally, research could shift focus from individual decision biases to social preferences and cultural factors.

Finally, I examined how a risk-averse newsvendor orders fewer units across different demand scenarios than a risk-neutral newsvendor and identified the types of demand distributions each prefers. A reasonable extension of this thesis would be to investigate a risk-seeking newsvendor or to incorporate loss aversion while simultaneously examining additional behavioral factors, such as environmental consciousness.

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## A Appendix

The numerical analysis was conducted using Google Colab (Python). The document, which includes all results, tables, and graphs used in this thesis, as well as additional plots and values not explicitly discussed in the thesis, is available upon request. These supplementary details provide further insights and can be referenced for a deeper understanding of the analysis. The code is thoroughly commented to ensure that the methodology and rationale are transparent and easy to follow.

# Selbstständigkeitserklärung

Ich erkläre hiermit, dass ich diese Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche gekennzeichnet. Mir ist bekannt, dass andernfalls der Senat gemäss Artikel 36 Absatz 1 Buchstabe o des Gesetzes vom 5. September 1996 über die Universität zum Entzug des aufgrund dieser Arbeit verliehenen Titels berechtigt ist.

Bern, 05.11.2024

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(Unterschrift)