



The role of commitment in optimal stopping

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ABSTRACT

We investigate the role of commitment in optimal stopping theory by studying all the variants between Prophet Inequality (PI) and Pandora's Box (PB). Both problems deal with a set of variables drawn from known distributions. In PI the gambler observes an adversarial order of these variables with the goal of selecting one that maximizes the expected value against a prophet who knows the exact values realized. The gambler has to irrevocably decide at each step whether to select the value or discard it (commitment). On the other hand, in PB the gambler selects the order of inspecting the variables and for each pays an observation cost to see the actual value realized, aiming to choose one to maximize the net cost of the value chosen minus the observation cost paid. The gambler in PB can return and select any variable already seen (no commitment).

For all variants arising by changing the following 3 parameters: commitment, observation cost, and order selection, we summarize known results and fill gaps for unstudied cases. Our main contribution is uncovering a connection between the minimization variant with observation cost but no order selection and the Ski-Rental problem, which allows us to establish a tight competitive ratio of $\frac{e}{e-1}$. We also clarify how these parameters interact to shape the competitive ratio across all variants.

1. Introduction

Optimal stopping problems such as Prophet Inequality (PI) and Pandora's Box (PB) arise naturally in settings where decisions must be made sequentially under uncertainty such as pricing, online auctions, and search problems (e.g. housing search, hiring decisions, and consumer search). They capture the fundamental trade-off between accepting a current option with limited information and continuing the search at the risk of losing past opportunities or incurring observation costs.

These problems formalize this trade-off in distinct ways. In Prophet Inequality a gambler is sequentially presented with n independent samples $X_1, \dots, X_n$ drawn from known distributions $\mathcal{D}_1, \dots, \mathcal{D}_n$ and must irrevocably decide at each step to either select the sample (stopping) or discard it forever. The gambler's reward is $\mathbb{E}_{\mathcal{D}}[X_{\tau}]$ where τ is the time she decides to stop and her goal is to compete with a prophet who can see all the realized values in advance (achieving $\mathbb{E}_{\mathcal{D}}[\max_{i \in [n]} X_i]$ for the maximization version [1,2], or $\mathbb{E}_{\mathcal{D}}[\min_{i \in [n]} X_i]$ for minimization [3]). In

contrast, Pandora's Box [4] gives the gambler control over the inspection order and the ability to revisit past samples, but each observation incurs cost c_i . The gambler's goal is to maximize $\mathbb{E}_{\mathcal{D}}[\max_{i \in \mathcal{O}} X_i - \sum_{i \in \mathcal{O}} c_i]$ (or to minimize $\mathbb{E}_{\mathcal{D}}[\min_{i \in \mathcal{O}} X_i + \sum_{i \in \mathcal{O}} c_i]$ in the minimization version) where $\mathcal{O}$ denotes the set of inspected samples. While PI enforces *commitment* (no turning back) at no observation cost and competes against a Prophet who knows all realized values, PB relaxes the commitment constraint but introduces observation costs and competes with the *online optimal* (the best strategy without knowing realized values). We evaluate performance using the competitive ratio defined as $\inf_I \frac{\mathbb{E}[\text{ALG}(I)]}{\mathbb{E}[\text{OPT}(I)]}$ for maximization and $\sup_I \frac{\mathbb{E}[\text{ALG}(I)]}{\mathbb{E}[\text{OPT}(I)]}$ for minimization, where ALG is the gambler's algorithm and OPT is the respective benchmark and I is any instance.

More generally, between Pandora's Box and Prophet Inequalities, the problems are characterized by 3 parameters: commitment (whether the gambler must select the last seen sample or can revisit earlier ones),

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Table 1

Best known ratios for all eight variants of the **minimization** version of the problem. The ratio of 1.58 noted with a * **also** holds for a weaker prophet that knows the values but not the order of arrival. For the commitment case, all combinations have ratio ∞ as given in [3].

Commitment	Yes	No		
Best Ratio	∞	∞	1.58*	1
Reference/Result	B.1 in [3]	3.1, [4]	3.1	4.1 (trivial)
Order Selection	Yes/No	Yes	No	Yes/No
Observation Cost	Yes/No	Yes	Yes	No

Table 2

Best known ratios for all eight variants of the **maximization** version of the problem. In the case of commitment, no observation cost and order selection (*free order prophet*) the lower bound 0.7258 is from [5] and the upper bound $1/1.342 \approx 0.745$ is from [6].

Commitment	Yes	No			
Best Ratio	0	[0.726, 0.745]	1/2	0	1
Reference/Result	4.2	[5,6]	[2]	4.2	4.1 (trivial)
Order Selection	Yes/No [7]	Yes	No	Yes/No	Yes/No
Observation Cost	Yes	No	No	Yes	No

observation cost (whether inspecting a sample incurs a cost) and order selection (whether the gambler controls the inspection order or it is adversarially determined). While many variants of PB and PI have been studied, the broader space between these problems remains underexplored. This raises a natural question: *how do these parameters interact to shape the competitive ratio, and can we uncover unifying principles that explain the behavior across all variants?*

Our contribution. A central insight is that the minimization variant with observation cost but no order selection reduces to a **generalized** Ski-Rental problem, where the gambler faces decreasing buy costs over time. We show that the gap between the online optimal and the prophet is **exactly** $e/(e-1)$ by carefully constructing an i.i.d. instance which also quantifies the *cost of uncertainty*: how much better can someone with no information do when the order is fixed. However, when order selection is allowed, the ratio becomes infinite since the prophet can exploit i.i.d. distributions to create an optimal inspection sequence (see [Example 3.1](#)). Additionally, we systematically explore all variants between Pandora's Box and Prophet Inequality clarifying how the three parameters (commitment, order selection, and observation cost) affect the competitive ratio. The results for all different variants are summarized in [Tables 1](#) and [2](#), with our contributions in **bold**.

2. Preliminaries

Pandora's box. The formulation of Pandora's Box [4] described a greedy algorithm that achieves the optimal expected cost. This algorithm applies to both minimization and maximization versions as shown by the alternative proof of reservation values by [8]. The core of this algorithm is the calculation of an index σ_b for every box b , called the *reservation value*, defined as the value satisfying

$$\mathbb{E}_{v \sim D_b}[(s(v - \sigma_b))^+] = c_b, \quad \begin{cases} s = +1, \text{ maximization} \\ s = -1, \text{ minimization} \end{cases} \quad (1)$$

where $(a - b)^+ = \max(0, a - b)$. The boxes are then ordered by decreasing σ_b (maximization) or increasing σ_b (minimization), and opened sequentially until the best observed value exceeds (resp. falls below) the reservation value of the next box. The algorithm is formally described for the minimization version in [Algorithm 1](#).

Ski-rental [9]. In the ski rental problem, a gambler skis for an unknown number of days T , and has to daily choose to either rent (cost 1) or buy

Algorithm 1: Weitzman's algorithm (Minimization).

Input: Boxes with costs $c_b \in \mathbb{R}^+$, distribution $D = (D_1, D_2, \dots, D_n)$.

- 1 An unknown vector of values $v \sim D$ is drawn
- 2 Calculate σ_b for each box b using [Eq. \(1\)](#) and rename boxes such that $\sigma_1 \leq \sigma_2 \leq \dots \leq \sigma_n$
- 3 $V_{\min} \leftarrow \infty$
- 4 **for every** box $i = \{1, \dots, n\}$ **do**
- 5 Pay c_i , open box i and observe V_i
- 6 $V_{\min} \leftarrow \min(V_{\min}, V_i)$
- 7 **if** $V_{\min} < \sigma_{i+1}$ **then**
- 8 Stop and collect $V_{\min}$
- 9 **end**
- 10 **end**

the skis (cost B , but no further costs). The prophet knows the last ski day T , and therefore pays $\text{Ski-prophet} = \min(T, B)$.

3. Results for minimization

Theorem 3.1. *When there is observation cost, no commitment and no order selection, the Ski-Rental algorithm [9] obtains $\frac{e}{e-1} \approx 1.58$ and this ratio is tight.*

Proof. We first show the approximation ratio then the tightness.

Approximation ratio. Consider a variant of the Ski-rental problem called the *Decreasing Buying cost Ski-rental (DB-Ski Rental)* defined as follows: we are going skiing for an unknown number of days and each day t we can either rent the skis (for one day) paying 1 or buy them for the rest of the ski season for a_t , where $a_t \geq a_{t+1}$ for all times $t \geq 1$. The prophet in this problem can see the whole sequence, and therefore pays $\min_{i \leq t} (i + a_i)$. The traditional Ski-rental of [Section 2](#) is a special case of this variant, where $a_t = B$ until the final (unknown) ski day, then $a_t = 0$.

Observe that DB-Ski-rental is exactly the same as the optimal selection problem when there is observation cost but no commitment (i.e. the version of this theorem). To see this define $a_t = \min_{i \leq t} X_i$ i.e. the buying cost at step t is the minimum of all the variables seen so far, which is a decreasing sequence (as DB-Ski Rental requires). Any decision made by the DB-Ski-rental algorithm, directly translates to a decision in our problem;

- **If** DB-Ski-Rental rents (cost 1): inspect the next variable, pay 1.
- **Else** DB-Ski-Rental buys (cost a_t): stop and select X_p where $p = \arg\min_{i \leq t} X_i$, and pay the exact same cost. At this step we crucially use that there is no commitment, and we are allowed to turn back and select a variable (potentially) seen earlier.

Using Lemma 3.1 from [10], which we copy below for convenience, we get that there exists an algorithm that obtains $\frac{e}{e-1}$ for our problem.

Lemma 3.1 from [10] *Given any sequence $a_1 \geq a_2 \geq \dots$, there exists an online algorithm that chooses a stopping time t so that¹*

$$t - 1 + a_t \leq \frac{e}{e-1} \min_j (j - 1 + a_j). \quad (2)$$

The intuition for this lemma is that it treats the decreasing buying cost ski rental as a sequence of nested traditional ski rental problems, each triggered whenever a new, lower “buy cost + time” threshold is encountered.

¹ You may notice that in this lemma the time is shifted by 1 (i.e. we have $t - 1$ instead of t). This is a technicality to allow the player to stop before renting, by having an immediate outside option of cost a_1 . In our problem we set $a_1 = \infty$, to avoid allowing the player to stop without choosing anything, so that now X_1 corresponds to $t = 2$ and so on.

Furthermore, in Lemma 7.1 of [10] the authors extend Lemma 3.1 to the case where the renting costs p_i for each day i are not all 1 and Eq. (2) becomes

$$a_i + \sum_{j=1}^{i-1} p_j \leq \frac{e}{e-1} \min_j \left(a_j + \sum_{i=1}^{j-1} p_i \right). \quad (3)$$

Therefore, the factor of $\frac{e}{e-1}$ also holds for our problem for non-uniform unit costs.

Tightness. For this part, the following instance shows that we cannot do better than $\frac{e}{e-1}$. Consider the following i.i.d. instance with observation cost 1 and for $k = 1 \dots n$

$$X_k = \begin{cases} n & \text{w.p. } 1 - \frac{1}{n} \\ 0 & \text{w.p. } \frac{1}{n}. \end{cases}$$

Since the instance is i.i.d., it does not matter if we can select the order or not, and we know that the optimal online algorithm is Weitzman [4] (also described in Algorithm 1). We calculate the reservation value for all variables² using Eq. (1) to be $\sigma = n$. Weitzman's algorithm is therefore indifferent between stopping at the first variable and trying to find a 0, and assume without loss of generality that it chooses to play. The expected cost of the gambler then is $ALG = \mathbb{E}[\text{WEITZ}] = n$.³

We calculate the prophet's expected cost, using $q = \left(1 - \frac{1}{n}\right)$ for simplicity. Let $k \geq 1$, and call $T \in \{1 \dots, n\}$ the random time for which the first 0 appears; if there is no such a 0, set $T = n + 1$. We have for $1 \leq i \leq n$

$$\Pr[T = i] = \frac{1}{n} q^{i-1}. \quad (4)$$

We now calculate the cost of the prophet

$$\begin{aligned} \text{Ski-prophet} &= \sum_{i=1}^{n+1} \Pr[T = i] \min(i, n+1) \\ &= \sum_{i=1}^n i \cdot \Pr[T = i] + (n+1) \cdot \sum_{i=n+1}^{n+1} \Pr[T = i] \\ &= \sum_{i=1}^n \frac{i}{n} q^{i-1} + \frac{n+1}{n} \sum_{i=n+1}^{+\infty} q^{i-1} \quad \text{Using Eq. (4)} \\ &= n(1 - 2q^n) + (n+1)q^n \\ &= (n-1)(1 - q^n) + 1, \end{aligned}$$

where in the fourth equality we used again Eqs. (5) and (6) below for $k = n$.

$$\sum_{i=1}^k i q^{i-1} = \frac{1 + q^k(kq - k - 1)}{(1 - q)^2}. \quad (5)$$

$$\sum_{i=k+1}^n q^{i-1} = \frac{q^k}{1 - q}. \quad (6)$$

Putting it all together we have that

$$\frac{ALG}{\text{Prophet}} \geq \frac{n}{(n-1)(1 - q^n) + 1}.$$

The right-hand side term goes to $(1 - e^{-1})^{-1}$ when n tends to infinity, which proves the result.

A weaker prophet. Even if we compete against a weaker prophet who knows the values of the variables but not the order of arrival, we still cannot do better than $\frac{e}{e-1}$. The weak prophet stops at the first variable if there is no 0, which happens with probability $\left(1 - \frac{1}{n}\right)^n \approx \frac{1}{e}$, and tries to find a 0 otherwise. In the case there is no 0 Weitzman overpays by n . The cost of the prophet then is

$$\text{Weak-Prophet} = \mathbb{E}[\text{WEITZ}] - \frac{n}{e} = \mathbb{E}[\text{WEITZ}] \left(1 - \frac{1}{e}\right).$$

² Reservation value is the same for all variables since they are i.i.d. with the same cost.

³ Continuing and stopping has the same expected cost; if the algorithm stops at the first variable, on expectation it pays $1 + n(1 - 1/n) = n$.

Therefore $\mathbb{E}[\text{WEITZ}] \approx 1.58 \cdot \text{Weak-Prophet}$. $\square$

Proposition 3.1. When **there is** observation cost and order selection but **no** commitment, the competitive ratio for the minimization version is ∞ .

Proof. Consider the following i.i.d. instance:

$$X_k = \begin{cases} 0 & \text{w.p. } n^{-1/2} \\ n & \text{w.p. } 1 - n^{-1/2}, \end{cases}$$

for $k = 1, \dots, n$, and cost 1. Whenever there is a 0, the prophet will put it in first position, and pick it. Otherwise, he will pick the first variable. His payoff is then

$$\begin{aligned} \mathbb{E}[\text{Prophet}] &= \left(1 - (1 - n^{-1/2})^n\right) \cdot 1 + (1 - n^{-1/2})^n \cdot (n+1) \\ &= n \cdot (1 - n^{-1/2})^n + 1, \end{aligned}$$

therefore $\mathbb{E}[\text{Prophet}] \rightarrow 1$ as $n \rightarrow \infty$. For the gambler this is a Pandora's Box instance where all the boxes are the same. The optimal algorithm is Weitzman, so we calculate their reservation values $\sigma = n^{1/2}$, and the gambler should stop whenever the value found is $< n^{1/2}$, which only happens for 0. Therefore the gambler will continue until they find a 0, incurring cost

$$\begin{aligned} ALG &= \sum_{i=1}^n \Pr[\text{There is a 0 at } i] (i+0) + \Pr[\text{No 0 exists}] \cdot (n+n) \\ &= \sum_{i=1}^n n^{-1/2} \cdot (1 - n^{-1/2})^{i-1} \cdot i + (1 - n^{-1/2})^n \cdot 2n \\ &= n^{1/2} + (1 - n^{-1/2})^n (n - n^{1/2}) \approx n^{1/2}. \end{aligned}$$

Therefore the ratio is $ALG/\text{Prophet} = n^{1/2} \rightarrow \infty$ as n grows. $\square$

4. Results for maximization

Proposition 4.1. Whenever there is **no** commitment and **no** opening cost, the best ratio is 1.

Proof. The decision-maker and the prophet have the same optimal algorithm: open everything, without cost, and choose the best sample. This is true for both minimization and maximization. $\square$

Proposition 4.2. Whenever **there is** observation cost, in the maximization case, the competitive ratio is 0. This holds with or without commitment and with or without choosing the order.

Proof. The variables are all i.i.d. with observation cost 1 and for $k = 1, \dots, n$

$$X_k = \begin{cases} n & \text{w.p. } 1/n^{1.5} \\ 1 & \text{w.p. } 1 - 1/n^{1.5}. \end{cases}$$

Denote by $p = 1 - n^{-1.5}$. When all variables are realized as 1 the optimal will just stop at the first box (paying $1 - 1 = 0$), otherwise the gain is n and at each step i the probability of stopping is $\Pr[\text{stop at step } i] = p^{i-1}(1 - p)$. Therefore we calculate the gain of the prophet as

$$\begin{aligned} \text{Prophet} &= p^n \cdot 0 + (1 - p^n)n - \sum_{i=1}^n i \cdot \Pr[\text{stop at step } i] \\ &= n - \frac{1 - p^n}{1 - p} \quad \text{From Eq. (7)} \\ &= n - n^{1.5}(1 - p^n) \quad \text{Def of } p \text{ \& rearrange} \\ &\approx n - n^{1.5} \left(n^{-0.5} - \frac{1}{2n} \right) \quad \text{Exp limit \& Taylor} \\ &= \frac{n^{0.5}}{2n} > 0, \end{aligned}$$

where in the $\approx$ above we used that $p^n = (1 - n^{-1.5})^n \approx e^{-n^{-0.5}} \approx 1 - n^{-0.5} + 1/2n^{-1}$ from the exponential limit for n large and Taylor approximation. The algorithm can play any adaptive strategy, note however that (1) if n is observed, the algorithm will stop immediately and (2) if the algorithm

ever stops at a step when only 1s have been observed, then the payoff is < 0 and is worse than stopping immediately at the first step (and paying 0). Therefore, the algorithm will either try to find a n or stop at the first box getting in total

$$\begin{aligned} \text{ALG} &= \max \left\{ p - 1 + n(1 - p), p^n(1 - n) + (1 - p^n)n - \sum_{i=1}^n \Pr[\text{Stop at } i]i \right\} \\ &= \max \left\{ p - 1 + n(1 - p), p^n(1 - n) + n - \frac{1 - p^n}{1 - p} \right\} \\ &= \max \left\{ \frac{n - 1}{n^{1.5}}, p^n(1 - n - n^{1.5}) + n - n^{1.5} \right\} \text{ def of } p \text{ and rearrange} \\ &\rightarrow 0 \quad \text{as } n \text{ grows.} \end{aligned}$$

For both these calculations we used that

$$\begin{aligned} \sum_{i=1}^n i \cdot \Pr[\text{stop at step } i] &= \sum_{i=1}^n i \cdot (1 - p)p^{i-1} \\ &= \frac{1 - p^n - np^n + np^{n+1}}{1 - p} \\ &= \frac{1 - p^n}{1 - p} - np^n. \end{aligned} \quad (7)$$

Order selection. In the versions where the order can be chosen, the cost of the gambler will remain the same since the variables are all i.i.d. If all variables are 1 the prophet still just opens the first and stops, otherwise she opens first one of the boxes that give n and pay -1 . Therefore

$$\text{Prophet} = p^n(1 - 1) + (1 - p^n)(n - 1) > 0,$$

and the example still holds.

Commitment vs no-commitment. This example holds regardless of whether we have commitment or not. The only acceptable value is n ; when the n is found any reasonable algorithm stops immediately. If no n is found, the algorithm just takes the last 1 found, and there is no point returning and taking a different 1. $\square$

5. Conclusion/Final remarks

We make some final observations on the results presented.

- **Remark 1:** In the minimization version, being able to turn back and take an earlier option makes the approximation ratio from arbitrarily bad (first column of Table 1) to constant (last 3 columns of Table 1).
- **Remark 2:** Theorem 3.1 establishes the $\frac{e}{e-1}$ gap between the online optimal and the Prophet as **tight**, addressing a notoriously hard problem in the literature because of the complex structure of the online optimal (see e.g. [11,12]). Additionally, this is the only setting where

the Prophet's advantage over the online optimal remains constant, highlighting the uniqueness of the Ski Rental connection.

CRedit authorship contribution statement

José Correa: Writing – review & editing, Writing – original draft, Methodology, Formal analysis; **Evangelia Gergatsouli:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis; **Bruno Ziliotto:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis.

Data availability

No data was used for the research described in the article.

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