# The Value of Advance Perishability Information in Dynamic Inventory Control

**(Authors' names blinded for peer review)**

## 1. Introduction

Fresh perishables such as fruits, vegetables, and meat form a large and operationally important part of food supply chains. Managing these products is difficult not only because they are perishable, but also because their remaining shelf life is often uncertain. Unlike packaged perishables with explicit expiration dates, fresh products do not come with a precise sell-by clock. Units from the same batch may look similar when they enter storage but become unsellable on different dates. We show this evidence with an avocado shelf-life experiment. We obtained a single batch of 150 avocados and stored all samples under identical container conditions at 7°C. Spoilage first appeared on day 11 and continued through day 61. Visual inspection was also imperfect: an avocado could appear fresh and intact externally even after its internal pulp had perished. Figure 1 summarizes these two motivating features—lifetime dispersion and hidden internal deterioration.


**Figure 1 Shelf-life and internal perishability in avocados. Panel (a) reports the observed lifetime dispersion for one batch of 150 samples; panel (b) illustrates that an externally fresh appearance can mask internal spoilage.**

This creates a basic replenishment mismatch: overestimating sellable carryover can lead to under-ordering and lost sales, whereas underestimating it can lead to over-ordering, excess inventory, and waste. Recent advances in non-destructive sensing make this hidden inventory condition potentially observable before replenishment. Near-infrared spectroscopy is one such technology: spectral responses can be linked to internal quality attributes, and prior studies use spectroscopy or imaging methods to assess ripening, freshness, and shelf-life related attributes in fresh produce (Kasampalis et al. 2021). With sensing technology, a retailer could scan on-hand products before replenishment and know how much inventory will perish and how much will remain sellable, which we refer to as *Advance Perishability Information (API)*. This raises three research questions: How does API change replenishment decisions? How valuable is this information, and what features of perishability determine its value? Finally, how does API affect food waste?

Prior studies examine information about product age, remaining lifetime, and environmental conditions in perishable inventory systems (Ketzenberg and Ferguson 2008, Ketzenberg et al. 2015, Gaukler et al. 2017). These studies consider dynamic inventory systems, but the value of freshness-related information is primarily evaluated through numerical dynamic programming or simulation. The most closely related analytical work is Keskin et al. (2025), who study freshness transparency in a single-period newsvendor model. Thus, while freshness information has been studied computationally in dynamic systems and analytically in a single-period setting, its structural value in a dynamic replenishment system remains unclear.

We address this gap using a finite-horizon periodic-review inventory model. In each period, the retailer observes on-hand inventory $x_t$ and a random proportion $\tilde{\gamma}_t \in [0,1]$ determines how much carryover remains sellable; demand $\tilde{d}_t$ is also uncertain. Newly ordered units arrive fresh. In the *Baseline* system, the retailer knows the demand and perishability distributions but orders before observing $\gamma_t$; in the *API* system, $\gamma_t$ is observed before ordering while demand remains uncertain. We define the *value of advance perishability information (VAPI)* as the difference in optimal expected costs between the two systems. We analytically characterize the optimal replenishment policies and the structural and asymptotic properties of VAPI, and use numerical experiments to examine food waste.

## 2. Main Results

Our first result concerns the optimal replenishment policies. Under API, the retailer observes the realized sellable proportion $\gamma_t$ before ordering and follows a classical base-stock policy: $q_t^A(x,\gamma_t) = (\hat{s}_t^A - \gamma_t x)^+$. Under the Baseline system, the optimal order $q_t^B(x)$ is state-dependent and nonincreasing in on-hand inventory, but need not have a standard order-up-to form. The difference becomes important when inventory is large. Under API, every positive perishability realization eventually leaves sufficient sellable inventory and no order is needed. Under Baseline, the retailer may continue ordering to hedge against the possibility that all on-hand inventory becomes unsellable. We characterize three large-inventory behaviors: the Baseline order reaches zero at a finite threshold, converges to zero only asymptotically, or converges to a strictly positive hedge order.

Our second result characterizes VAPI. For period $t$ and inventory state $x$, $\Delta_t(x) = V_t^B(x) - V_t^A(x) \geq 0$. where $V_t^B$ and $V_t^A$ are the optimal expected costs under the Baseline and API systems, respectively. In the terminal-period problem, VAPI is increasing and convex in the low-inventory region and decreasing and convex in the no-order region. In the intermediate region, the Baseline retailer continues to order while the API retailer orders only under sufficiently low perishability realizations, so VAPI need not be unimodal. In the multi-period problem, we recover the low-inventory monotonicity and convexity and establish conditions under which the large-inventory monotonicity extends backward through the horizon.

Our third result identifies different drivers of VAPI across inventory states. When on-hand inventory is close to zero, incremental VAPI is driven by variation in perishability. Under regularity conditions, $\Delta_t(x) - \Delta_t(0) = \Theta(\mathrm{Var}(\tilde{\gamma}_t)x^2)$ , as $x \downarrow 0$. When inventory becomes large, the relevant distributional feature changes. Let $p_t = \mathbb{P}(\tilde{\gamma}_t = 0)$ denote the complete-spoilage probability. We show that VAPI converges to a limit $L_t$ $\lim_{x\to\infty} \Delta_t(x) = L_t$. where the limit depends on complete-spoilage risk and future information value. When positive survival can be arbitrarily close to zero, the convergence rate is governed by the lower tail of the perishability distribution and, dynamically, by products of successive perishability realizations. Thus, variance governs VAPI near zero inventory, whereas complete-spoilage risk and lower-tail behavior govern its large-inventory behavior.

We also examine food waste generated under the two information systems. Although API always weakly reduces expected inventory cost, it does not necessarily reduce food waste. After observing a severe perishability realization, the API retailer may replenish more aggressively than the Baseline retailer to avoid lost-sales, which can increase future inventory and waste. The numerical results show that API is more likely to reduce waste when demand is relatively predictable, perishability is sufficiently heterogeneous, and the lost-sales penalty induces the Baseline system to carry precautionary inventory. Thus, the economic value of perishability information and its environmental effect need not move in the same direction.

Figures 2 and 3 illustrate the main numerical implications of our analysis. Figure 2 plots VAPI $\Delta_t(x)$ for $t \in 1, 3, 5$ across Scenarios A–C, showing how its shape varies with the inventory state and how it approaches the large-inventory limit $L_t$ under different perishability and cost settings. Figure 3 reports the corresponding relative food waste reduction under API.

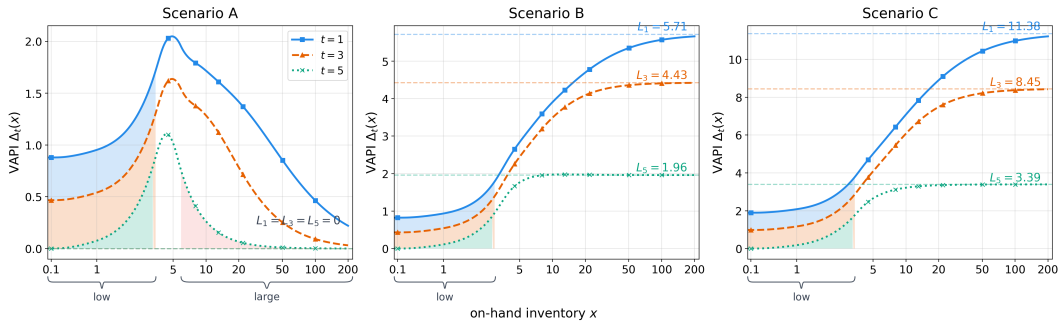


**Figure 2** **VAPI $\Delta_t(x)$ for $t \in \{1, 3, 5\}$ in Scenarios A, B and C. Shaded areas identify the classification inventory regions. Dashed horizontal lines indicate the asymptotic limits $L_t$.**

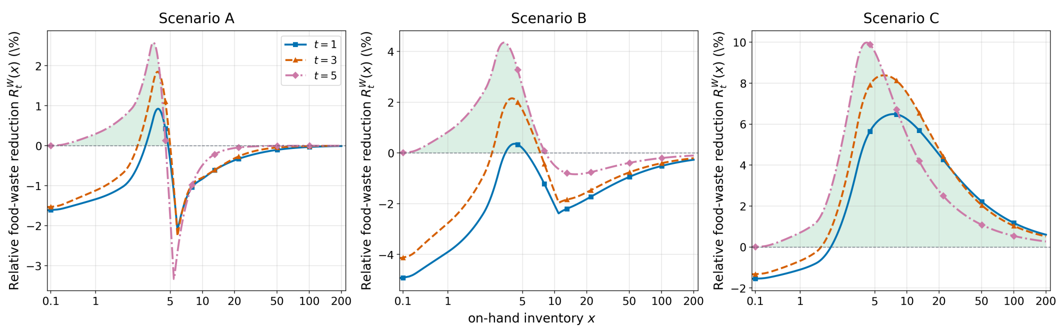


**Figure 3** **Relative food waste reduction for periods $t \in \{1, 3, 5\}$ across Scenarios A–C. Shaded areas identify the regions where API reduces food waste.**

# References


Kasampalis, D. S., Tsouvaltzis, P., Ntouros, K., Gertsis, A., Gitas, I., Siomos, A. S. 2021. The use of digital imaging, chlorophyll fluorescence and Vis/NIR spectroscopy in assessing the ripening stage and freshness status of bell pepper fruit. *Computers and Electronics in Agriculture* 187, 106265.

Ketzenberg, M., Ferguson, M. E. 2008. Managing slow-moving perishables in the grocery industry. *Production and Operations Management* 17(5), 513–521.

Ketzenberg, M., Bloemhof, J., Gaukler, G. 2015. Managing perishables with time and temperature history. *Production and Operations Management* 24(1), 54–70.

Gaukler, G., Ketzenberg, M., Salin, V. 2017. Establishing dynamic expiration dates for perishables: An application of RFID and sensor technology. *International Journal of Production Economics* 193, 617–632.

Keskin, N. B., Li, C., Song, J.-S. 2025. The blockchain newsvendor: Value of freshness transparency and smart contracts. *Management Science* 71(8), 6666–6682.

Keskin, N. B., Li, C., Song, J.-S. 2024. Innovator's edge in supply chain transparency and food waste reduction. *Working paper.*

Lu, T. 2026. Shipment monitoring, allocation and the impact on food waste. *Management Science*, forthcoming.