Imperfect Competition with Costly Disposal*

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Published at the International Journal of Industrial Organization
https://doi.org/10.1016/j.ijindorg.2022.102842

Abstract

This paper studies the effect of disposal costs on consumer surplus and firms' profits. First, we analyze a monopolist producing inventories either early on at a low cost and with little information about demand, or later with more information yet at a higher cost. Unsold products are discarded. The firm forgoes an early production cost advantage if and only if the disposal cost and demand uncertainty are both simultaneously high. Expected disposal decreases in its cost, yet the firm lowers its production to mitigate costs, resulting in lower expected profit and consumer surplus. Similar results hold for firms competing in sales volumes with unobserved inventories. Ex-ante symmetric firms may choose different production timings. The disposal cost substitutes information about demand, thereby affecting a firm's information advantage. Accordingly, a firm's expected profit may increase with the disposal cost. Firms may adjust their production timing, resulting in a discontinuous change in the expected profit and consumer surplus.

Keywords: Disposal, Inventory, Timing of Production, Uncertain Demand
JEL: D04, L11, L13, L50

*I thank Jean-Michel Benkert, Philipp Brunner, Giacomo Calzolari, Winand Emons, Yassine Lefouili, Igor Letina, Marc Möller, Sarah Spycher, Eva Zuberbühler, Laura Zwyssig, and three anonymous referees for helpful discussions and suggestions.

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1 Introduction

A wide variety of commodities are produced in advance. Firms manufacture their products anticipating future demand, determining inventories while their product's popularity is unknown. Accordingly, production costs are sunk by the time products are put up for sale. If demand turns out to be lower than expected, firms may hold back some quantity to increase the market price.

Investigative journalists have exposed several cases in which firms have discarded new, unsold products. One of the most infamous scandals was uncovered in 2010 by the New York Times: a Hennes and Mauritz (H&M) store in New York City discarded new clothes at their back entrance, cutting them up to make sure they would never be worn. The same course of action was used by a Nike store in 2017. In reaction to the negative headlines, firms usually pledge improvement, yet disposing of unsold products is an open secret in the fashion industry.[1]

This behavior, however, is not restricted to the apparel industry. French Amazon dumped almost 3 million unsold products in 2018. All over France, new products worth \$900 million are discarded each year.[2] The disposal of unused products is considered a waste of resources and an environmental burden, which led the French government to intervene.

In 2016, France already passed a law prohibiting grocery stores from disposing of food as long as it is still edible. With the new *loi anti-gaspillage* (anti-waste law), regulators are broadening the prohibition of disposal to non-food products, including textiles, electronics, and daily hygiene products. Unsold products must be donated or recycled.[3] The new regulation is expected to come into effect in 2023.

This paper studies how firms respond to a regulatory increase in their disposal costs and its effects on consumer surplus. The literature on this subject is scarce.[4] Environmental economists usually discuss policies to reduce waste and increase recycling, when the first welfare theorem fails due to externalities.[5] Instead of looking at an efficient mechanism to reduce disposal, we focus on the effect of costly disposal in a market with imperfect competition, thereby abstracting from externalities.

First, we study a monopolist that either produces early on at a low cost and with little information about demand, or later, with more information yet at a higher cost. Demand is linear and consists of an unknown number of identical consumers. If demand

[1] Not all firms keep it a secret. Burberry literally burnt almost \$40 million of stock in 2018. The fashion brand reported the deed in their annual report and specified that the energy was used to make the process environmentally friendly.

[2] According to an estimate by the government. `https://www.nytimes.com/2019/06/05/world/europe/france-unsold-products.html`

[3] Projet de loi relatif à la lutte contre le gaspillage et à l'économie circulaire (TREP1902395L).

[4] The literature on operation research studies the optimal inventory called the newsvendor problem, e.g., Rosenfield (1989) or van der Laan and Salomon (1997).

[5] See for example Dinan (1993).

is lower than expected, the firm can hold back quantities to increase the market price. Restrained or unsold products are not perfectly reversible; firms may even incur a per-unit cost to dispose of irreversible commodities.[6] Each unsold unit is, therefore, not only a loss in revenue, it also increases costs. By slight abuse of language, we refer to the loss from the imperfect reversibility and the additional cost of discarding as disposal cost.

We find that the expected quantity of disposal is reduced if its cost goes up. Moreover, the monopolist decreases its production volume to reduce costs if demand is lower than expected. In our setup, this results in a lower expected trade volume, a lower expected profit and lower consumer surplus.

The firm forgoes the cost advantage from an early production if and only if the disposal cost and demand uncertainty are both simultaneously high: Low disposal costs substitute information about demand. If the disposal cost tends to zero, i.e., the inventory becomes fully reversible, the outcome is equivalent to the firm having full information about demand. The monopoly produces its inventory equal to the profit-maximizing quantity for the greatest possible demand. If a lower demand materializes, the monopolist reverses parts of its inventory and again sells the profit-maximizing quantity, equivalent to as if the firm had known its demand. Information about demand is, therefore, more valuable if the disposal is costly.

Second, we study the same setup with two firms competing in sales volumes. The larger the disposal cost, the less is discarded by firms. Thus, given its inventory, a firm competes more fiercely for a larger market share if the disposal is costly, thereby benefiting consumers. However, firms adjust their inventory strategy in response to costly disposal. They decrease their production to mitigate costs if demand is lower than expected. Disposal decreases, yet consumers are negatively affected. Firms, furthermore, may adjust their timing of production.

Three types of equilibria in pure strategies exist: (i) If demand is highly uncertain and discarding is expensive, both firms produce on the spot. They forgo an early production cost advantage and delay their production until they have full information. (ii) If demand is reasonably predictable and/or the marginal cost of disposing of is lower than the marginal cost advantage, both firms produce in advance at a low cost. An increase in the disposal cost reduces the expected disposal, yet it also lowers expected consumer surplus and firms' expected profits. (iii) For intermediate levels of demand uncertainty and a disposal cost above the marginal cost advantage, one firm produces in advance, while the other produces on the spot. The first manufactures at a lower cost, yet the latter has an information advantage. The former's reaction to a low

[6] For example, a machine may be disassembled in its components; a disposal cost is avoided, and selling or reusing the components can cover some costs. By contrast, a loaf of bread can not be reverted to flour, and a disposal cost may accrue if it is discarded.

demand is expensive if the disposal cost is high. Due to this costly reaction, the information advantage is more valuable if disposal is expensive, resulting in a higher (lower) expected profit of the latter (former). The profits' order is ambiguous. The higher the disposal cost, the lower the expected disposal. Expected consumer surplus, however, is also lower. Moreover, firms may adjust their timing of production, resulting in profits and consumer surplus changing discontinuously.[7]

We extend our model in several directions. We consider firms with a combined production technology: Firms first manufacture their inventory at low costs while demand is uncertain. Then, both firms react to new information about demand either by disposing of or producing additional quantities.[8] Again, firms only produce after the realization of demand if the disposal cost and demand uncertainty are both simultaneously high.

This result on the forgoing of the cost advantage hinges, to some extent, on the price being below the marginal cost of production. We alter the demand function by allowing firms to dispose of products by offering them for free. For high demand uncertainty, firms produce in advance, regardless of the cost to discard.

Moreover, we study observed inventories. Costly disposal has the additional effect that the firm with a larger inventory can credibly commit to selling large parts of it. Opposing to the cost effect, this benefits the leader resulting in a U-shaped expected profit. The smaller firm produces (mainly) after the realization of demand. Its information advantage is more valuable with costly disposal, resulting in a higher expected profit. Consequently, both firms' profits may increase in the disposal cost, yet consumer surplus decreases.

Finally, we discuss different forms of competition, namely, perfect competition and price competition. In general, a regulatory increase in the disposal cost lowers the quantity discarded. Yet, the expected trade volume decreases, harming consumers.

Related Literature. This paper stands at the intersection of many strands of literature. In his seminal paper, Saloner (1986) provides one of the first formal studies of imperfect competition with disposal costs. Inventory is not fully reversible, and firms may even incur additional costs for unsold products.[9] First, firms choose (simultaneously or sequentially)[10] their inventory, which is observed by their competitor and later compete in sales volume. Since there is no demand uncertainty, in the end, firms

[7] The equilibrium in pure strategies is unique, except for type (iii), where an equivalent equilibrium exists with the firms' labels interchanged.

[8] We extend the model to $N \geq 2$ firms – consumer surplus increases in the number of firms, yet the disposal does too, resulting in a trade-off between competition and the quantity discarded.

[9] Pashigian (1988) showed that clearance sale prices are below marginal costs in the apparel industry, presenting empirical evidence for the imperfect reversibility.

[10] Pal (1993) argues that the sequential outcome arises as a realization of a symmetric equilibrium in mixed strategies. By contrast, Maggi (1996) predicts a sequential outcome in pure strategies.

dispose of nothing. The higher the disposal cost, the more credible it is not to discard, even if the price is low, i.e., observable inventories indicate intended sales.

However, if firms produce facing an uncertain demand, they may hold back some products to affect the market-clearing price (Dada and van Mieghem 1999). In Anupindi and Jiang (2008) flexible firms produce after the demand realization; inflexible firms produce ex-ante. Firms trade off the value of commitment against flexible production.

The literature on inventory usually assumes a weakly lower production cost in the second period due to the employed capital's opportunity cost. For example, Arvan (1985), Saloner (1987), and Mitraille and Moreaux (2013) study storing cost, making earlier production more expensive. The stored commodities' production cost is sunk, resulting in a effective marginal cost of zero in the next stage. Firms seek leadership at the cost of storing the commodity. Sales volume increases, resulting in a lower market price if firms can store.

By contrast, Thille (2006) finds in an infinitely repeated game that storage does not affect prices in the absence of depreciation. With depreciation, firms incur higher costs to maintain their stock of inventory, resulting in lower sales and higher market prices. Although we do not explicitly model a storage cost in our setup, it would decrease the cost advantage of early production. As in the latter, this reduces sales and the price goes up.

Pal (1991) allows for different production costs across periods. If the cost increases over time, a unique subgame perfect equilibrium in pure strategies exists. Firms seek leadership due to the inventory's strategic effect, as above, and in addition, production costs are lower.[11] We silence this strategic effect by studying unobserved inventories.

Similarly, Montez and Schutz (2021) study a game in which firms cannot observe their competitor's inventory. They compete in prices and may hold back some of their quantities. When the production cost tends to be fully recoverable, i.e., products become perfectly reversible, the allocation ends in Bertrand competition. The authors conclude that the observability of the inventories determines the difference between the Cournot and Bertrand outcomes. Their conclusion is based on the seminal paper by Kreps and Scheinkman (1983), in which they show that capacity choice followed by price competition yields an outcome equivalent to the Cournot outcome.[12]

The literature on strategic forward sales discusses the role of observability in more detail. If there exists a forward market, Allaz and Vila (1993) demonstrate an increase in competition if inventories are observable, while Hughes and Kao (1997) find no effect

[11] Recently, different effects of inventory have been studied in the literature: Antoniou and Fiocco (2019) analyze the stockpiling of consumers, Mitraille and Thille (2014) study speculators, and Dana and Williams (2019) and Qu et al. (2018) discuss intertemporal price discrimination.

[12] The result depends on the rationing rule (see, e.g., Davidson and Deneckere, 1986), furthermore a pure strategy equilibrium may not exist if uncertainty is introduced (e.g., Hviid, 1991 or Reynolds and Wilson, 2000). By analyzing differentiated products, Young (2010) avoids a rationing rule and supports the Cournot equivalence.

on the competitiveness if forward sales are not observed. Ferreira (2006) studies the case of imperfect observability and finds that the presence of a future market results in a more competitive outcome. Comparing firms' profits with and without observed inventory yields ambiguous results in our setup.

Our model may also be interpreted as one in which firms either acquire full information on demand at a unit cost or renounce from the acquisition. The literature on information acquisition in imperfectly competitive markets usually assumes a cost to reduce the demand uncertainty, which is, however, independent of the sales volume (e.g., Li et al. 1987, Vives 1988, Hwang 1993). In Sasaki (2001) firms pay a fixed cost to learn about demand. One firm's information acquisition discourages the competitor's incentive to acquire information. Firms, however, cannot react to the materialized demand.

We follow Hamilton and Slutsky (1990) and have a pre-game stage where firms choose their production technology/timing without committing to quantities. By contrast, Gal-Or (1985) studies a sequential move game and finds, in general, a first-mover advantage in submodular games. If demand is uncertain, the second mover can infer some information of the first mover's action (Gal-Or, 1987). Thus, the second mover may have an advantage. In Liu (2005) and Wang and Xu (2007), demand uncertainty decreases over time. In their setup, the firm producing in the second stage makes a higher profit if its information advantage is large. However, the authors implicitly assume an infinitely high disposal cost. If the other firm can adjust its sales volume to the realization of demand, their result remains only partially.

In these papers, the second mover observes the first mover's action perfectly. If there exists some noise, Bagwell (1995) shows that the general first-mover advantage disappears, and there exists a unique equilibrium in pure strategies. However, van Damme and Hurkens (1997) prove the existence of a mixed equilibrium, resembling the outcome of the observable game. In our setup, the first mover has to choose another action, simultaneously with the second mover, in the game's final stage. We conjecture that this results in a unique equilibrium, as in our model. This, however, needs to be addressed in detail as part of future research.

In our setup, ex-ante symmetric firms may choose different strategies, as in Robson (1990). According to van Damme and Hurkens (1999), a sequential move equilibrium is only stable if the first mover has a cost advantage. Additionally, we require a follower's information advantage and imperfect reversibility of production for the existence of an asymmetric equilibrium.

2 Monopoly

Let us consider a monopolist producing a single commodity. The inverse demand function is linear with a random slope, reflecting an unknown number of identical consumers. Formally, let the inverse demand function in state $\vartheta \in \{l, h\}$ be $P_\vartheta(Q) = a - b_\vartheta Q$, where Q is the total sales volume. The intercept $a > 0$ denotes the maximal willingness to pay and is commonly known. The slope b_ϑ takes on one of two values, $b_l = 1 + \beta$ or $b_h = 1 - \beta$, each with equal probability. The difference between the states is measured by $\beta \in [0, 1)$, which we refer to as demand uncertainty. If b_h materializes, more consumers are on the market, resulting in a higher willingness to pay for any quantity. Therefore, we refer to b_h (b_l) as the high (low) demand state. With this setup, the expected inverse demand function is independent of β.[13]

The monopoly can choose between two different production technologies. It either produces the quantity $\bar{q}_A$ in the first period at a marginal cost normalized to zero, denoted as technology A, or postpones its production until the demand has materialized and manufactures $q_{S,\vartheta}$ at a marginal cost $c \in [0, a/2)$, which we denote as technology S. Thus, technology A represents a low-cost yet time-consuming production, while technology S stands for a fast, yet more expensive production.

Producing at an early stage is less expensive; a firm has time to adjust processes to substitute input factors. For example, a firm can off-shore its production to decrease its costs.[14] However, physical products have to be transported, resulting in longer processes. Production, therefore, has to precede in time. The firm trades off costs and uncertainty: producing at a lower cost with less information or deferring the manufacturing until more information is available, yet production is more expensive.

If the monopolist produces with technology A, it can hold back its goods after the demand has materialized. Let the firm's sales volume be $q_{A,\vartheta}$, thus $\bar{q}_A - q_{A,\vartheta}$ is the quantity held back. We denote its marginal cost as $d > 0$, reflecting costs to dispose of products.

Due to the normalization of technology A's production cost to zero, we have to be careful with the interpretation of the parameters. The production cost of technology S, c, is the relative cost advantage of early production. The disposal cost, d, also reflects the reversibility of the production: Suppose technology A's production cost is c_A. For $d \in [-c_A, 0)$, a part of the inventory is reversible. [15] Thus, by normalizing $c_A = 0$,

[13]Commonly, demand uncertainty is modeled with a linear demand curve and a random intercept (e.g., Gilpatric and Li, 2015) or a random slope (e.g., Daughety and Reinganum, 1994, or Malueg and Tsutsui, 1996). We discuss a random intercept in Appendix A. Klemperer and Meyer (1986), argue that firms facing a random slope prefer to fix quantities and let prices adjust to the demand state. Similarly, in our model, firms fix quantities and let prices adjust if the disposal cost is high.

[14]Firms outsource their production to countries with low labor or material cost, such as China or India (Deloitte, 2016). However, there also exists other strategic motives, e.g., Buehler and Haucap (2006) or Milliou (2019).

[15]For example, products are reused or sold in a clearance sale.

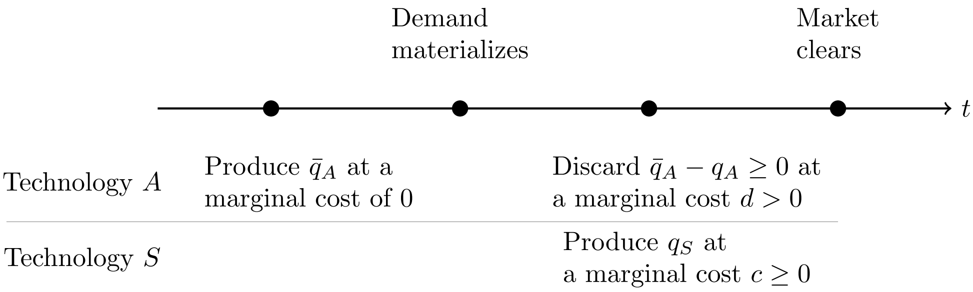


Figure 1: The game's timeline.

we do not have to distinguish between reversibility and additional costs of discarding. Nonetheless, a small d should be interpreted as a largely reversible product.

Figure 1 summarizes the technologies. Henceforth, we suppress the state index ϑ for quantities. Formally, the expected profits of the two technologies are

$$\mathbb{E}[\pi_{A,\vartheta}(q_A, \bar{q}_A)] = \mathbb{E}[P_\vartheta(Q)q_A - d(\bar{q}_A - q_A)], \tag{1}$$

$$\mathbb{E}[\pi_{S,\vartheta}(q_S)] = \mathbb{E}[P_\vartheta(Q)q_S - cq_S], \tag{2}$$

where Q is the total sales volume; (1) refers to technology A and (2) to S.

Suppose the monopolist uses technology A. After the realization of demand, the inventory $\bar{q}_A$ is fixed and the production cost is sunk. The monopolist's sales volume $q_A \in [0, \bar{q}_A]$ maximizes

$$\pi_{A,\vartheta}(q_A|\bar{q}_A) = P_\vartheta(Q)q_A - d(\bar{q}_A - q_A), \tag{3}$$

where $Q = q_A$. The optimal sales volume $q_A(\bar{q}_A) = \min\{(a + d)/2b_\vartheta, \bar{q}_A\}$ is anticipated by the firm when it produces its inventory. The profit maximizing inventory and sales volume are summarized in Table 1. We indicate the market outcome with a star.

In the high-demand state, the monopolist sells its total inventory. If demand is lower than expected, it reduces its quantity to increase the market price. The costlier disposal is, the higher is the cost to reduce the quantity. To mitigate costs in the low-demand state, the monopolist lowers its inventory, resulting in less disposal. This, however, comes at the cost of a lower profit in the high-demand state.

For $d \geq \beta a$, the monopolist disposes of nothing and serves the expected demand, regardless of its realization. A low maximal willingness to pay, a, implies a relatively expensive production, i.e., costly products are not discarded.

A low disposal cost substitutes information about demand: If the monopolist knew the demand in advance, it would produce $\bar{q}_A^* = a/2b_\vartheta$. This equals the sales volume in Table 1 for $d = 0$, i.e., when the firm's inventory is perfectly reversible. The monopolist produces its inventory for the high-demand state. If a lower demand materializes, the monopolist reverses parts of its inventory, and the output is equivalent as if the firm

q_A^*	high demand	low demand
$d < \beta a$	$\frac{a-d}{2(1-\beta)}$	$\frac{a+d}{2(1+\beta)}$
$d \geq \beta a$	$\frac{a}{2}$	$\frac{a}{2}$

Table 1: A monopoly's sales volume. The inventory equals the sales volume in the high-demand state.

had known its demand. Accordingly, information about demand is more valuable if the disposal is costly.

The monopolist's expected profit producing with technology A is

$$\mathbb{E}[\pi_A^*] = \begin{cases} \frac{(a+d)^2}{8(1+\beta)} + \frac{(a-d)^2}{8(1-\beta)}, & \text{if } d < \beta a; \\ \frac{a^2}{4}, & \text{if } d \geq \beta a. \end{cases} \quad (4)$$

Technically, this is a submodular function in β and d: the higher the demand uncertainty in a market, the more strongly the firm's expected profit is affected by the disposal cost.

Next, suppose the monopolist uses technology S instead. The firm produces $q_S^* = (a-c)/2b_\vartheta$ in order to maximize (2), resulting in the expected profit $\mathbb{E}[\pi_S^*] = (a-c)^2/4(1-\beta^2)$. Comparing this to (4) yields that the firm chooses technology S if and only if

$$\beta \geq \begin{cases} \frac{2ac-c^2+d^2}{2ad}, & \text{if } d < \sqrt{c(2a-c)}; \\ \frac{\sqrt{c(2a-c)}}{a}, & \text{if } d \geq \sqrt{c(2a-c)}. \end{cases}$$

Note that for $d \leq c$, the right-hand-side of the inequality is larger than 1. Thus with a low d and/or a low β, the firm uses technology A: it goes for the cost advantage of early production and manufactures facing uncertain demand. The following proposition summarizes this result.

Proposition 1. *The monopolist forgoes an early production cost advantage if and only if the disposal cost d and demand uncertainty β are both simultaneously high.*

With the monopolist's technology choice and the associated production and sales volumes, we can analyze the effect of an increase in the disposal cost.

Proposition 2. *The monopolist's expected profit*

$$\mathbb{E}[\pi^*] = \begin{cases} \frac{(a+d)^2}{8(1+\beta)} + \frac{(a-d)^2}{8(1-\beta)}, & \textit{if } d < \beta a \leq \frac{2ac-c^2+d^2}{2d}; \\ \frac{a^2}{4}, & \textit{if } \beta a \leq \min\{d, \sqrt{c(2a-c)}\}; \\ \frac{(a-c)^2}{8(1+\beta)} + \frac{(a-c)^2}{8(1-\beta)}, & \textit{else,} \end{cases}$$

expected consumer surplus $\mathbb{E}[CS^*] = \mathbb{E}[\pi^*]/2$ *and expected disposal*

$$\mathbb{E}[\bar{q}_A^* - q_A^*] = \begin{cases} \frac{\beta a - d}{2(1-\beta^2)}, & \textit{if } d < \beta a \leq \frac{2ac-c^2+d^2}{2d}; \\ 0, & \textit{else,} \end{cases}$$

decrease with the disposal cost d*. The expected price is not affected by the disposal cost.*

The monopolist's expected profit decreases with d: a cost increase lowers the profit. On the one hand, consumers benefit from a higher sales volume in the low-demand state; on the other hand, consumers are harmed by the lower production resulting in a lower sales volume in the high-demand state.[16] The second effect dominates the first, decreasing the expected consumer surplus. Finally, a lower production quantity and a higher sales volume in the low-demand state results in lower disposal. However, the disposal cost only has an effect if it is low relative to the demand uncertainty.

3 A Model of Competition

In this section, we introduce a second firm to our setup. To guarantee that both firms are active in equilibrium, we assume a relatively large willingness to pay, formally $a \geq 2c + d$. Otherwise, one firm may end up with zero sales volume. Note that this condition is independent of b_ϑ, i.e., in our setup a random slope instead of a random demand intercept simplifies the analysis.

The game proceeds as follows. In stage 0, the two competitors simultaneously choose their production technology A or S, and the choice is observed. In stage 1, firms with technology A produce $\bar{q}_A$, which is not observed by the competitor. Then, demand materializes. In stage 2, firms simultaneously choose their sales volume $q_A \in [0, \bar{q}_A]$, or produce their sales volume q_S if they use technology S. Finally, the market clears.

We have to distinguish between four subgames following the technology choice: both firms choose technology A (A, A), both choose technology S (S, S), and one chooses technology A and the other technology S (A, S) and (S, A). By the symmetry of the game, the latter two differ only in the firms' labels.

We derive the perfect Bayesian equilibrium in pure strategies. Therefore, we first derive each subgame's unique equilibrium, starting with the symmetric ones.

[16]Formally, consumer surplus $CS_\vartheta = Q(a - P_\vartheta(Q))/2$.

Symmetric Subgames. We denote one firm by i and the other by j. Let us start with the (A, A) subgame, i.e., both firms produce in advance. To simplify notation, we suppress the technology index A. Formally, firm i's strategy is $(\bar{q}_i, q_{i,\vartheta}(\bar{q}_i))$, with $\bar{q}_i \in \mathbb{R}^+$ and $q_{i,\vartheta} : \mathbb{R}^+ \to \mathbb{R}^+$.

Production costs are sunk after the realization of demand; both firms take their inventory as given. Both choose their sales volume $q_i \in [0, \bar{q}_i]$ to maximize (3) with $Q = q_i + q_j$. The best response function of firm i can be written as

$$q_i(q_j|\bar{q}_i) = \min\left\{\max\left\{\frac{a+d}{2b_\vartheta} - \frac{1}{2}q_j, 0\right\}, \bar{q}_i\right\}. \tag{5}$$

A firm can maximally sell its total inventory. Its best response function weakly decreases in the competitor's sales volume. Note that (5) increases with d for any q_j and $\bar{q}_i$: The costlier disposal, the less is discarded. If inventories are fixed and the disposal cost goes up, firms compete more fiercely for larger market shares.

Firms do not observe their competitor's inventory. Nonetheless, each firm anticipates its own disposal behavior. Formally, the firms choose their inventory $\bar{q}_i \geq 0$ to maximize (1) subject to (5). Firm i's best response is

$$\bar{q}_i(q_{j,l}, q_{j,h}) = \begin{cases} \frac{a-d}{2(1-\beta)} - \frac{q_{j,h}}{2}, & \text{if } q_{j,h} - q_{j,l} \leq \frac{2(\beta a - d)}{1-\beta^2}; \\ \frac{a}{2} - \frac{(1+\beta)}{4}q_{j,l} - \frac{(1-\beta)}{4}q_{j,h}, & \text{if } \frac{2(\beta a-d)}{1-\beta^2} \leq q_{j,h} - q_{j,l} \leq \frac{2(\beta a+d)}{1-\beta^2}; \\ \frac{a-d}{2(1+\beta)} - \frac{q_{j,l}}{2}, & \text{if } q_{j,h} - q_{j,l} \geq \frac{2(\beta a+d)}{1-\beta^2}, \end{cases} \tag{6}$$

whenever it is positive. We derive the best response function explicitly in Appendix B. In the first case, firm i sells its inventory in the high-demand state and disposes of parts of it if demand is below expectations. In the second case, the firm sells its entire inventory in both states. In the third case, the firm disposes of parts of its inventory in the high-demand state and sells it entirely in the low-demand state; this is never part of an equilibrium.

We summarize the subgame's equilibrium sales volumes in Table 2. In the high-demand state, firms sell their total inventory, which decreases with d. In the low-demand state, firms dispose of parts of it if $d < \beta a$. Firms dispose of less, when the disposal is more costly. Consequently, the sales volume in the low-demand state goes up with d. If $d \geq \beta a$, nothing is thrown away and firms sell their total inventory regardless of the demand's realization.

In equilibrium, firms have to play a best response. There is a unique equilibrium: this is also perfect Bayesian, and firms have correct beliefs about their competitor's inventory. With this, we summarize the market outcome in the following Lemma.

q_A^*	high demand	low demand
$d < \beta a$	$\frac{a-d}{3(1-\beta)}$	$\frac{a+d}{3(1+\beta)}$
$d \geq \beta a$	$\frac{a}{3}$	$\frac{a}{3}$

Table 2: The firms' sales volume in the (A, A) subgame. Inventory equals the sales volume in the high-demand state.

Lemma 1. *In the (A, A) game's unique perfect Bayesian equilibrium, firms choose $\bar{q}_{A,i} = \max\{(a-d)/3(1-\beta), a/3\}$, $q_{A,i,\vartheta}(\bar{q}_{A,i}) = \min\{(a+d)/3b_\vartheta, \bar{q}_{A,i}\}$, and have correct beliefs about the competitor's inventory.*

A firm's expected profit

$$\mathbb{E}[\pi_A^*] = \begin{cases} \frac{(a-d)^2}{18(1-\beta)} + \frac{(a+d)^2}{18(1+\beta)}, & \text{if } d < \beta a; \\ \frac{a^2}{9}, & \text{if } d \geq \beta a, \end{cases} \tag{7}$$

expected consumer surplus $\mathbb{E}[CS_A^*] = 2\mathbb{E}[\pi_A^*]$, and expected disposal

$$2\mathbb{E}[\bar{q}_A^* - q_A^*] = \begin{cases} \frac{2(\beta a - d)}{3(1-\beta^2)}, & \text{if } d < \beta a; \\ 0, & \text{if } d \geq \beta a, \end{cases}$$

all decrease with the disposal cost d. The expected price $\mathbb{E}[P_A^*] = a/3$ is not affected by the disposal cost.

Expected disposal goes down with its cost. Firms' profits decrease with d because any adjustment to a lower-than-expected demand is costly, and firms compete more fiercely. However, the expected consumer surplus also decreases: firms decrease their inventory and, thus, the expected sales volume. The negative effect of the lower inventories dominates the positive effect of fiercer competition.

Next, we derive the equilibrium of the (S, S) game. Firms manufacture on the spot, thus delaying their production until demand has materialized. Both firms choose $q_{S,i,\vartheta} \in \mathbb{R}^+$ to maximize (2), i.e., the firms play a Cournot game in each demand state. Again, we suppress the technology index. Their best response is

$$q_{i,\vartheta}(q_{j,\vartheta}) = \max\left\{\frac{a-c}{2b_\vartheta} - \frac{1}{2}q_{j,\vartheta}, 0\right\}. \tag{8}$$

By contrast to the best response in (5), the sales volume is no longer bound from above. Firms incur a marginal cost of production c instead of the disposal cost d. Formally, the disposal cost is like a negative production cost, as can be seen by comparing (5)

q_1^*	high demand	low demand
$d < \beta\frac{a+c}{2}$	$\frac{a-2d+c}{3(1-\beta)}$	$\frac{a+2d+c}{3(1+\beta)}$
$d \geq \beta\frac{a+c}{2}$	$\frac{a+c}{3}$	$\frac{a+c}{3}$

Table 3: The first mover's sales volume. Inventory equals the sales volume in the high-demand state.

to (8). Instead of incurring a cost for each unit sold, firms with a disposal cost incur a cost for each unit unsold.

The subgame's unique equilibrium sales volumes are $q^*_{S,\vartheta} = (a-c)/3b_\vartheta$. Since firms produce with full information, nothing is disposed of, and d has no effect. The following Lemma summarizes this finding.

Lemma 2. *In the (S,S) game's unique equilibrium, firms choose $q_{S,i,\vartheta} = (a-c)/3b_\vartheta$.*
A firm's expected profit

$$\mathbb{E}[\pi^*_S] = \frac{(a-c)^2}{9(1-\beta^2)}, \tag{9}$$

expected consumer surplus $\mathbb{E}[CS^*_S] = 2\mathbb{E}[\pi^*_S]$, and the expected price $\mathbb{E}[P^*_S] = (a+2c)/3$ are not affected by the disposal cost. Firms produce with full information, therefore, nothing is disposed of.

Asymmetric Subgames. Let us turn to the asymmetric subgames. One firm produces with technology A, while the other uses technology S. We denote the former as first mover (she), indexed by 1, and the latter as second mover (he), indexed by 2. Her strategy is $(\bar{q}_{A,1}, q_{A,1,\vartheta}(\bar{q}_{A,1}))$, with $\bar{q}_{A,1} \in \mathbb{R}^+$ and $q_{A,1,\vartheta} : \mathbb{R}^+ \to \mathbb{R}^+$; his is $q_{S,2,\vartheta} \in \mathbb{R}^+$. Her expected profit is given by Equation (1) and his expected profit by Equation (2), with $Q_\vartheta = q_{A,1,\vartheta} + q_{S,2,\vartheta}$. Again, we suppress the technology and state index.

When demand has materialized, the first mover's production cost is sunk. She chooses her sales volume $q_1 \in [0, \bar{q}_1]$ to maximize (3), yielding the best response function given by (5). The second mover does not observe her inventory. Yet, the first mover anticipates her optimal disposal behavior. She maximizes (1) subject to (5), resulting in the optimal production quantity given by (6).

The second mover produces after the demand's realization. Accordingly, his best response function is (8). There exists a unique equilibrium, which also forms a perfect Bayesian equilibrium, where the second mover has correct beliefs about the first mover's inventory.

Table 3 summarizes the first mover's production and sales volumes. For $d \leq \beta(a+c)/2$, she decreases her inventory if the disposal cost goes up. In the high-demand state,

q_2^*	high demand	low demand
$d < \beta\frac{a+c}{2}$	$\frac{a+d-2c}{3(1-\beta)}$	$\frac{a-d-2c}{3(1+\beta)}$
$d \geq \beta\frac{a+c}{2}$	$\frac{a-2c}{3(1-\beta)} + \beta\frac{a+c}{6(1-\beta)}$	$\frac{a-2c}{3(1+\beta)} - \beta\frac{a+c}{6(1+\beta)}$

Table 4: The second mover's sales volume depending on the demand state.

the first mover sells her total inventory. In the low-demand state, her sales volume increases in order to decrease the quantity discarded. Accordingly, she gives up some profit in the high-demand state to mitigate costs if demand is low. If $d \geq \beta(a+c)/2$, nothing is thrown away.

The second mover's sales volume given in Table 4 moves in the opposite direction: if the first mover decreases her sales volume, the second mover increases his and vice versa. In the high-demand state, the first mover's sales volume goes down with d; thus, the second mover faces a smaller competitor and increases his sales volume. In the low-demand state, however, she sells more the higher the disposal cost is. Accordingly, he lowers his sales volume to keep prices at a profitable level. The assumption $a \geq 2c + d$ ensures that the second mover's sales volume is positive. Entry blocking is thus not possible for relatively low costs.

We summarize the equilibrium and the disposal cost's effect on the market outcome in the following Lemma.

Lemma 3. *In the (A, S) and (S, A) games' unique perfect Bayesian equilibrium the first mover chooses*

$$\begin{aligned}
\bar{q}_{A,1} &= \max\{(a-2d+c)/3(1-\beta), (a+c)/3\}, \\
q_{A,1,h}(\bar{q}_{A,1}) &= \min\{\max\{(a-2d+c)/3(1-\beta), (a+c)/3\}, \bar{q}_{A,1}\}, \textit{ and} \\
q_{A,1,l}(\bar{q}_{A,1}) &= \min\{(a+2d+c)/3(1+\beta), (a+c)/3, \bar{q}_{A,1}\}.
\end{aligned}$$

The second mover chooses $q_{2,h} = \min\{(a+d-2c)/3(1-\beta), (2a-4c+\beta(a+c))/6(1-\beta)\}$ and $q_{2,l} = \max\{(a-d-2c)/3(1+\beta), (2a-4c-\beta(a+c))/6(1+\beta)\}$; he has correct beliefs about her inventory.

The first mover's expected profit

$$\mathbb{E}[\pi_1^*] = \begin{cases} \frac{(a-2d+c)^2}{18(1-\beta)} + \frac{(a+2d+c)^2}{18(1+\beta)}, & \textit{if } d < \beta\frac{a+c}{2}; \\ \frac{(a+c)^2}{9}, & \textit{if } d \geq \beta\frac{a+c}{2}, \end{cases} \tag{10}$$

expected consumer surplus

$$\mathbb{E}[CS^*_{AS}] = \begin{cases} \frac{(2a-d-c)^2}{36(1-\beta)} + \frac{(2a+d-c)^2}{36(1+\beta)}, & \textit{if } d < \beta\frac{a+c}{2}; \\ \frac{(4a-2c-\beta(a+c))^2}{144(1-\beta)} + \frac{(4a-2c+\beta(a+c))^2}{144(1+\beta)}, & \textit{if } d \geq \beta\frac{a+c}{2}, \end{cases} \tag{11}$$

and expected disposal

$$\mathbb{E}[\bar{q}^*_1 - q^*_1] = \begin{cases} \frac{\beta(a+c)-2d}{3(1-\beta^2)}, & \textit{if } d < \beta\frac{a+c}{2}; \\ 0, & \textit{if } d \geq \beta\frac{a+c}{2}, \end{cases}$$

all decrease with the disposal cost d. The expected price $\mathbb{E}[P^*_{AS}] = (a+c)/3$ *is not affected by the disposal cost, while the second mover's expected profit*

$$\mathbb{E}[\pi^*_2] = \begin{cases} \frac{(a+d-2c)^2}{18(1-\beta)} + \frac{(a-d-2c)^2}{18(1+\beta)}, & \textit{if } d < \beta\frac{a+c}{2}; \\ \frac{(2a-4c+\beta(a+c))^2}{72(1-\beta)} + \frac{(2a-4c-\beta(a+c))^2}{72(1+\beta)}, & \textit{if } d \geq \beta\frac{a+c}{2}, \end{cases} \tag{12}$$

increases with the disposal cost.

As in the symmetric subgames, the expected price is not affected by the disposal cost; it only reflects production costs. In Lemma 1 both firms have zero production costs, in Lemma 2 both incur the cost c, and in Lemma 3 one has zero cost, while the other has the cost c. The materialized price, however, depends on d: The price is higher in the high-demand state and the difference between the materialized prices increases with d. Firms incur a larger cost to adjust their sales volume to the realization of demand. By contrast, if d is small, firms inexpensively adjust to the materialized demand, thereby absorbing the demand's effect on the price.

Expected disposal decreases with its cost. The first mover's reaction to a low demand becomes costlier the higher d; the second mover's information advantage becomes more valuable. The competitors' profits, therefore, respond to an increase in the disposal cost in opposite directions. If the inventory is, however, observable, the disposal cost may increase both firms' profits simultaneously. We discuss this case in Section 4.

By assumption, the first mover has a lower production cost, while the second has an information advantage. The ordering of profits is thus ambiguous. She has an advantage if either the disposal cost is low, demand uncertainty is low, or both.

With fully reversible inventories, the second mover's information advantage is worthless. The first mover bears no cost to decrease her quantity in response to a low demand while having a lower production cost. By contrast, if she has no cost advantage, he expects a higher profit than the first mover. In the knife-edge case of no cost advantage and fully reversible inventory, both firms earn the same expected profit.

Equilibrium. A firm chooses the technology that maximizes its expected profit. Accordingly, we use the expected profits in Lemmas 1, 2, and 3 to derive the equilibrium. Given that one firm uses technology S, the other firm also uses technology S if $\mathbb{E}[\pi_S^*] \geq \mathbb{E}[\pi_1^*]$. Thus, we can define the threshold function $\beta_S(d) := \{\beta | \mathbb{E}[\pi_S^*] = \mathbb{E}[\pi_1^*]\}$, where the first mover is indifferent between technology A and S. The closed form can be written as

$$\beta_S(d) = \begin{cases} \frac{ac+d^2}{d(a+c)}, & \text{if } d < \sqrt{ac}; \\ \frac{2\sqrt{ac}}{(a+c)}, & \text{if } d \geq \sqrt{ac}. \end{cases}$$

Similarly, we define the threshold function $\beta_A(d) := \{\beta | \mathbb{E}[\pi_A^*] = \mathbb{E}[\pi_2^*]\}$ such that the second mover is indifferent between technology A and S, i.e.,

$$\beta_A(d) = \begin{cases} \frac{c}{d}, & \text{if } d < \sqrt{\frac{c(a+c)}{2}}; \\ \frac{2\sqrt{4a^2d^2+(a+c)(5a-7c)(4ac-4c^2+d^2)}-4ad}{(a+c)(5a-7c)}, & \text{if } \sqrt{\frac{c(a+c)}{2}} \leq d < 4a\sqrt{\frac{c(a-c)}{9a^2-2ac-7c^2}}; \\ 4\sqrt{\frac{c(a-c)}{9a^2-2ac-7c^2}}, & \text{if } d \geq 4a\sqrt{\frac{c(a-c)}{9a^2-2ac-7c^2}}. \end{cases}$$

Note that for $d \leq c$, both thresholds are larger than 1. Consequently, if production is largely reversible, both firms choose technology A regardless of the demand's uncertainty. We summarize this finding and the firms' equilibrium production technology by the following proposition.

Proposition 3. *A unique subgame perfect equilibrium in pure strategies exists,*[17]

(i) if $\beta > \beta_S(d)$: both firms produce with technology S;

(ii) if $\beta < \beta_A(d)$: both firms produce with technology A.

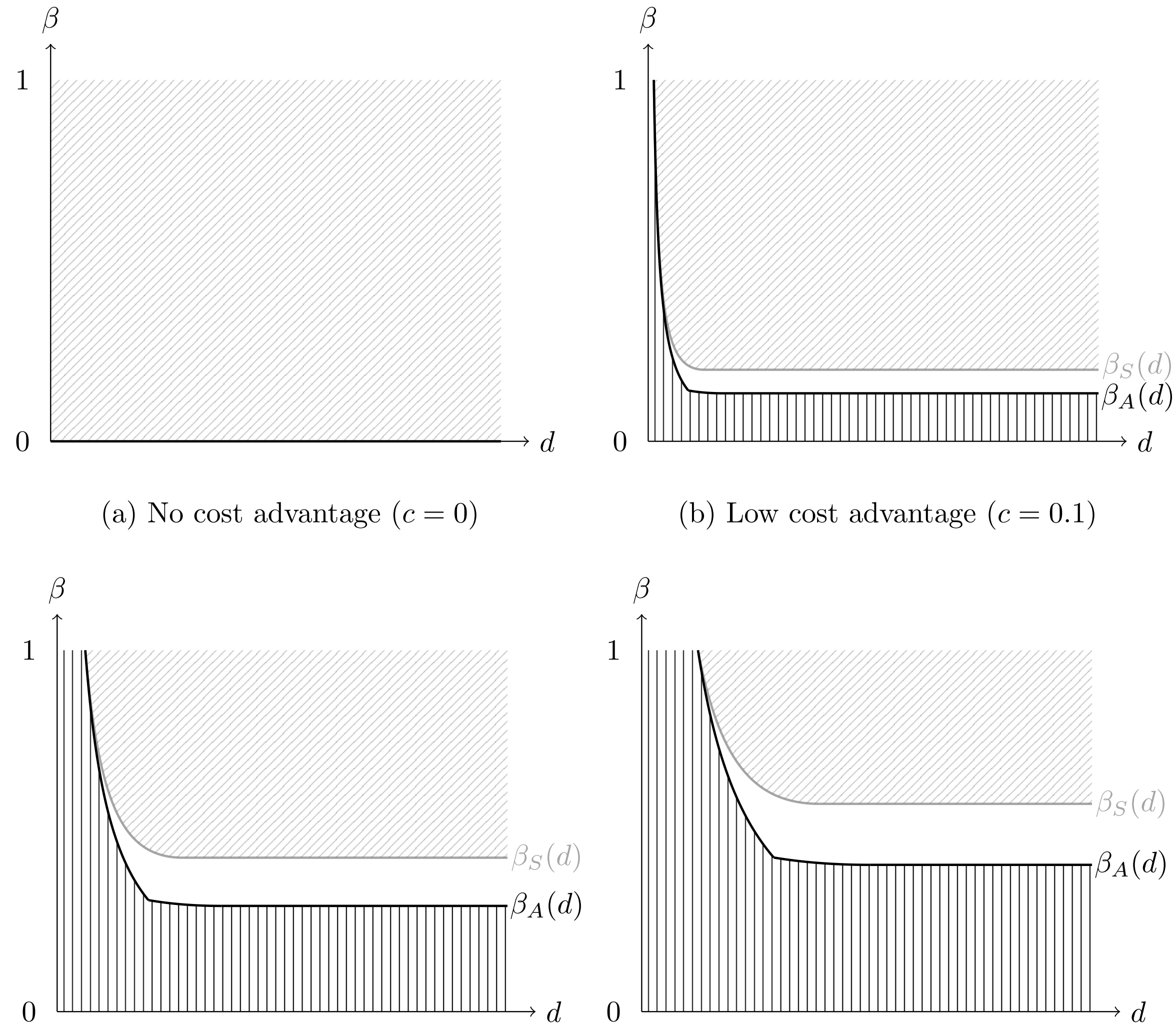
(iii) Otherwise, i.e. $\beta \in (\beta_A(d), \beta_S(d))$, one firm produces with technology A, while the other produces with technology S.

Firms forgo an early production cost advantage if and only if the disposal cost d and demand uncertainty β are both simultaneously high.

Figure 2 illustrates the result of Proposition 3. The threshold functions decrease with d: the less expensive the reaction to the demand's realization, the less relevant the information about demand becomes. Each type of equilibrium may exist depending on the parameters. Moreover, no types coexist apart from the threshold function.[18]

[17] If $\beta \in \{\beta_S(d), \beta_A(d)\}$, multiple equilibria exist.

[18] In (*iii*) there exists a symmetric equilibrium in mixed strategies. The probability of Strategy S being played increases with d. This results from decreasing expected profits of technology A, precisely $\mathbb{E}[\pi_A^*]$ and $\mathbb{E}[\pi_1^*]$, combined with increasing expected profits of technology S, precisely $\mathbb{E}[\pi_2^*]$. In the web appendix, we show that the firms' expected profits in the mixed equilibrium are non-monotonic.



(a) No cost advantage ($c = 0$)

(b) Low cost advantage ($c = 0.1$)

(c) Medium cost advantage ($c = 0.5$)

(d) High cost advantage ($c = 1$)

Figure 2: In the diagonally gray (vetically black) shaded area, both firms produce with technology S (A). In the white area, firms choose an asymmetric strategy: one chooses A and the other S. (Demand intercept $a = 10$ and the abscissa is truncated at 8.)

Similar to a monopoly, a firm only forgoes the cost advantage of an early production if the disposal cost and the demand uncertainty are both simultaneously high. If one of the two is low, both firms use technology A and produce in advance. Finally, an asymmetric equilibrium only exists if all three of the following conditions hold. (i) there is a cost advantage from early production, (ii) demand is uncertain, and (iii) disposal is costly (i.e., products are not fully reversible).

Comparative Statics. Lemmas 1, 2, and 3 already show that although disposal goes down with its cost, there is generally a negative effect on expected consumer surplus and profits. On the one hand, firms dispose of less and compete more fiercely for market shares. Yet, on the other hand, inventories are lower. Firms give up some profit in the high-demand state to mitigate costs if demand is below expectations. The expected trade volume, therefore, decreases with d, and so does consumer surplus.

The only market participant profiting from an increasing disposal cost is the second mover in the asymmetric equilibrium. Costlier disposal increases the value of his information advantage.

It remains to analyze how consumers and firms are affected if an increase in the disposal cost leads to a change of the production technology. For example, firms may relocate their manufacturing location in response to an increasing disposal cost.

The following proposition shows how expected disposal, expected consumer surplus, and firm's expected profits are affected by a (regulatory) increase of the disposal cost. It is useful to invert the threshold function by $d_S(\beta) := \min\{d|\beta_S(d) = \beta\}$. Thus, at $d_S(\beta)$ the first mover is indifferent between technology A and S. Similarly, the second mover is indifferent between technology A and S at $d_A(\beta) := \min\{d|\beta_A(d) = \beta\}$.

Proposition 4. *An increase in the disposal cost*

(i) decreases the expected disposal;

(ii) decreases expected consumer surplus, except if:

1. *the first mover postpones her production closer to the market. At $d = d_S(\beta)$, expected consumer surplus increases discontinuously;*

(iii) decreases firms' expected profits, except if:

1. *one firm postpones its production, becoming a second mover. At $d = d_A(\beta)$, the first mover's expected profit increase discontinuously;*
2. *in the asymmetric equilibrium, the second mover's expected profit increases.*

Finally, let us discuss the disposal cost's effect throughout all types of equilibria, starting at a low d, such that both firms produce in advance. An increase in the disposal cost decreases both firms' profits: If demand is below expectations, an increase in d induces firms to dispose of less, and thereby, compete more intensively for a larger market share. Moreover, firms decrease their inventory to mitigate costs if demand is low, resulting in a lower sales volume in the high-demand state.

Less disposal and fierce competition benefit consumers. However, a lower sales volume decreases consumer surplus. The latter effect is stronger than the former, resulting in an expected loss in consumer surplus.

At $d = d_A(\beta)$, a firm, labeled as firm 2, expects the same profit with technology S as with technology A. By definition of the equilibrium, firm 2's expected profit is continuous: he decides to postpone his production at $d_A(\beta)$, where $\mathbb{E}[\pi_2^*] = \mathbb{E}[\pi_A^*]$. The first mover's profit, however, increases discontinuously. The change of the competitor's technology yields a cost advantage for her. Although the second mover has superior information about demand, the first mover has an advantage for a low disposal cost, because it enables an inexpensive reaction to the state of demand.

Expected consumer surplus decreases discontinuously due to the technology change. While both firms produce in advance, they compete at equal strength and sell their total inventory if demand is above expectations. Now, in the asymmetric subgame, the first mover still sells her total inventory in the high-demand state. However, the second mover has monopoly power on the residual demand, decreasing consumer surplus.

The first mover's inventory decreases with costlier disposal, resulting in an increase in the second mover's residual demand. Expected consumer surplus, therefore, decreases further with d. The second mover's market power increases, and, additionally, his information advantage becomes more valuable, resulting in a higher expected profit. At the same time, the first mover's profit decreases due to her cost increase. Consequently, at some point, the second mover expects a higher profit than the first.

At $d = d_S(\beta)$, the first mover's expected profit is continuous. She postpones her production and gives up her cost advantage to gain information about demand. The second mover's profit decreases discontinuously; he loses his monopoly power on the residual demand. Additionally, he loses his information advantage, which is relatively valuable for a high disposal cost. Firms become equal and compete for the total demand, benefiting consumers. Consumer surplus, thus, increases discontinuously at $d_S(\beta)$.

When both firms produce with technology S, the disposal cost no longer has an effect. Firms only produce after demand has materialized. Therefore, no products are discarded, and the disposal cost is irrelevant.

Our discussion, however, only applies for high demand uncertainty. An increase in d does not always result in a technology change, as can be seen in Figure 2: for low demand uncertainty, it is not possible to affect the timing of production such that both firms (or even one) postpone it.

4 Extensions

In this section, we discuss several extensions. First, we allow firms to use a combination of the production technologies. Second, we alter the demand function and assume it is perfectly elastic at a price of zero. Then, we discuss changes if firms do observe their competitor's inventory. Finally, we discuss alternative forms of competition, namely perfect competition or price competition.

Production Technology. Firms can use both production technologies simultaneously. Formally, stage 0 does not exist. First, firms produce their inventories $\bar{q}_i \geq 0$ at zero marginal cost. After the demand has materialized, firms either dispose of at a marginal cost $d > 0$ or produce an additional quantity at the marginal cost

$c \in [0, (a-d)/2)$. Firm i's expected profit is

$$\mathbb{E}[\pi(q_i, \bar{q}_i)] = \mathbb{E}[P_\vartheta(Q)q_i - c\max\{q_i - \bar{q}_i, 0\} - d\max\{\bar{q}_i - q_i, 0\}],$$

with $Q = q_i + q_j$. The first term is the revenue, the second is the cost of additional production, and the third is the disposal cost.

In the second stage, firms take their inventories as given. They choose their sales volume $q_i \geq 0$ to maximize

$$\pi(q_i|\bar{q}_i) = P_\vartheta(Q)q_i - c\max\{(q_i - \bar{q}_i, 0\} - d\max\{(\bar{q}_i - q_i, 0\}, \tag{13}$$

resulting in the best reply

$$q_i(q_j|\bar{q}_i) = \max\left\{\min\left\{\max\left\{\frac{a+d}{2b_\vartheta} - \frac{1}{2}q_j, 0\right\}, \bar{q}_i\right\}, \frac{a-c}{2b_\vartheta} - \frac{1}{2}q_j\right\}. \tag{14}$$

As in above, the sales volume increases with the disposal cost. The costlier it is to discard, the more fiercely firms compete for their market share. We maintain the assumption that inventories are not observed by the competitor. Firm i therefore chooses her inventory $\bar{q}_i$ to maximize (13) subject to (14). We derive the best response in Appendix B. For $d < c$, it is

$$\bar{q}_i(q_{j,l}, q_{j,h}) = \begin{cases} \frac{a-d}{2(1-\beta)} - \frac{q_{j,h}}{2}, & \text{if } q_{j,h} - q_{j,l} \leq \frac{2(\beta a - d)}{1-\beta^2}; \\ \frac{a}{2} - \frac{(1+\beta)}{4}q_{j,l} - \frac{(1-\beta)}{4}q_{j,h}, & \text{if } \frac{2(\beta a - d)}{1-\beta^2} \leq q_{j,h} - q_{j,l} \leq \frac{2(\beta a + d)}{1-\beta^2}; \\ \frac{a-d}{2(1+\beta)} - \frac{q_{j,l}}{2}, & \text{if } q_{j,h} - q_{j,l} \geq \frac{2(\beta a + d)}{1-\beta^2}, \end{cases} \tag{15}$$

and for $c < d$, it is

$$\bar{q}_i(q_{j,l}, q_{j,h}) = \begin{cases} \frac{a+c}{2(1+\beta)} - \frac{q_{j,l}}{2}, & \text{if } q_{j,h} - q_{j,l} \leq \frac{2(\beta a - c)}{1-\beta^2}; \\ \frac{a}{2} - \frac{(1+\beta)}{4}q_{j,l} - \frac{(1-\beta)}{4}q_{j,h}, & \text{if } \frac{2(\beta a - c)}{1-\beta^2} \leq q_{j,h} - q_{j,l} \leq \frac{2(\beta a + c)}{1-\beta^2}; \\ \frac{a+c}{2(1-\beta)} - \frac{q_{j,h}}{2}, & \text{if } q_{j,h} - q_{j,l} \geq \frac{2(\beta a + c)}{1-\beta^2}, \end{cases} \tag{16}$$

whenever the inventory is larger than zero.

Note that if the marginal production cost is higher than the disposal cost, i.e., $d < c$, the function is equivalent to (6), where the firm has no access to technology S anymore. With the combined technology, firms can produce in the second stage and thus may lower their inventory.

In the first case of (16), the firm produces additional quantities if demand is higher than expected and sells its entire inventory in the low-demand state. In the second case, it sells the inventory in both states. In the third, it produces additional quantities in the low-demand state; this is never part of an equilibrium.

q_i^*	high demand	low demand
$d < \min\{\beta a, c\}$	$\frac{a-d}{3(1-\beta)}$	$\frac{a+d}{3(1+\beta)}$
$\beta a \leq \min\{c, d\}$	$\frac{a}{3}$	$\frac{a}{3}$
$c < \min\{\beta a, d\}$	$\frac{a-c}{3(1-\beta)}$	$\frac{a+c}{3(1+\beta)}$

Table 5: The firms' sales volume with combined technologies. Inventory equals the sales volume in the high (low) demand's state if $d < \min\{\beta a, c\}$ ($c < \min\{\beta a, d\}$).

If $c = d$, producing an additional quantity comes at the same cost as discarding one. Multiple inventory levels may therefore be optimal. The equilibrium inventory strategy may not be unique nor symmetric in this case. However, the resulting sales volumes of the firms are equivalent among all equilibria and independent of the inventory. The outcome is, therefore, uniquely determined.

The unique sales volumes are derived in Appendix B and shown in Table 5. For $c = d < \beta a$, firms produce any inventory $\bar{q}_i^* \in [(a+c)/3(1+\beta), (a-d)/3(1-\beta)]$ and sell the volumes given in the first/last row of the table, i.e., all result in the same outcome.

With a low disposal cost, firms sell their inventory in the high-demand state and dispose of parts of it if demand is below expectations. The equilibrium is equivalent to the one in the last section: firms decrease their inventories as a response to an increase in the disposal cost in order to mitigate costs if demand is below expectations. By contrast, if the production cost in the second period is low, firms sell their inventory in the low-demand state and produce additional quantities if demand is higher than expected. If disposal and production are costly, firms sell their inventory regardless of the demand's realization.

We summarize the firms' expected profits, consumer surplus, disposal, and the price in the following proposition.

Proposition 5. *The unique perfect Bayesian equilibrium is* $\bar{q}_i = \max\{(a-d)/(3(1-\beta)), a/3\}$, *if* $d < c$, *and* $\bar{q}_i = \min\{a/3, (a+c)/(3(1+\beta))\}$, *if* $d > c$, *and* $q_i(\bar{q}_i) = \max\{\min\{(a+d)/3b_\vartheta, \bar{q}_i\}, (a-c)/3b_\vartheta\}$*; firms have correct beliefs. A firm's expected profit*

$$\mathbb{E}[\pi_i^*] = \begin{cases} \frac{(a-d)^2}{18(1-\beta)} + \frac{(a+d)^2}{18(1+\beta)}, & \textit{if } d < \min\{\beta a, c\}; \\ \frac{a^2}{9}, & \textit{if } \beta a \leq \min\{c, d\}; \\ \frac{(a-c)^2}{18(1-\beta)} + \frac{(a+c)^2}{18(1+\beta)}, & \textit{if } c < \min\{\beta a, d\}, \end{cases} \tag{17}$$

expected consumer surplus $\mathbb{E}[CS^*] = 2\mathbb{E}[\pi_i^*]$, *and expected disposal*

$$2\mathbb{E}[\bar{q}_i^* - q_i^*] = \begin{cases} \frac{2(\beta a - d)}{3(1-\beta^2)}, & \text{if } d < \min\{\beta a, c\}; \\ 0, & \text{else}, \end{cases}$$

all decrease with the disposal cost d*. The expected price* $\mathbb{E}[P^*] = a/3$ *is not affected by the disposal cost.*

In the last section, some market participants (rarely) profited from an increase in the disposal cost due to an information advantage or a change in the production technology. With this setup, however, all participants are weakly worse off. Firms always go for a symmetric production, and as in the last section, in a symmetric equilibrium, all participants pay the price for a higher disposal cost.

Competition for market shares in the low-demand state increases with d. However, firms lower their production, resulting in a lower expected trade volume. The expected disposal also decreases with its cost, and the expected price is not affected.

Firms only use the production possibility after the demand's realization if the cost advantage is relatively low compared to the disposal cost and the demand uncertainty. If there is no demand uncertainty, there is obviously no need for a more expensive production ex-post. A low disposal cost substitutes information about demand. If a firm can reverse large shares of its production, it would rather produce too much than too little. Thus, although having access to both technologies A and S, the firms only use the latter if the disposal cost and demand uncertainty are both high.

Corollary 1. *Firms use the production cost advantage for their inventory. They forgo an early production cost advantage for a higher quantity if and only if the disposal cost* d *and demand uncertainty* β *are both simultaneously high.*

In the web appendix, we extend this setup to $N \geq 2$ firms. Expected consumer surplus increases in the number of firms, yet so does expected disposal. An increasing number of firms leads to a more competitive market, but it also leads to a higher number of disposers. Total expected disposal decreases more strongly in its cost, the larger the number of firms.

Firms expect a lower profit if the disposal cost increases. Accordingly, some firms may leave the market, resulting in a lower number of competitors. Competition is lowered, thereby additionally decreasing consumer surplus. The firms staying in the market are negatively affected by the higher disposal cost, yet benefit from fewer competitors. Their expected profits may thus increase. The positive effect of a lower discarded amount and, thereby, more intense competition for market shares is not noticeable for consumers. Moreover, considering firms' exits, competition may even decrease in response to increased disposal costs.

Perfectly Elastic Demand. Our result hinges, to some extent, on prices being potentially below zero. For sufficiently large demand uncertainty β, the price may be negative in the low-demand state. This is, per se, not a problem, because we normalized the marginal production cost in the first stage to zero. If demand is low, the price may indeed be below the marginal production cost.

However, for a sufficiently low price, demand may become perfectly elastic. Thus, firms may get rid of their goods by giving them away to consumers without further lowering the price. This gives rise to a new strategy for a firm using technology A. Before, firms did not produce large quantities in order to avoid significant losses in the low-demand state. Now, instead of disposing of a share of their inventory if demand is below expectations, they can offer the total quantity on the market to mitigate their costs.

To address this issue, we modify the demand function to $P_\vartheta(Q) = \max\{a - b_\vartheta Q, 0\}$.[19] We incorporated this demand function into our model in Section 2, a monopolist producing either with technology A or S. The formal derivation and the results are in Appendix A. Moreover, we study a monopolist with the combined technology and competitive firms with the combined technology.[20] The formal derivation is in the web appendix.

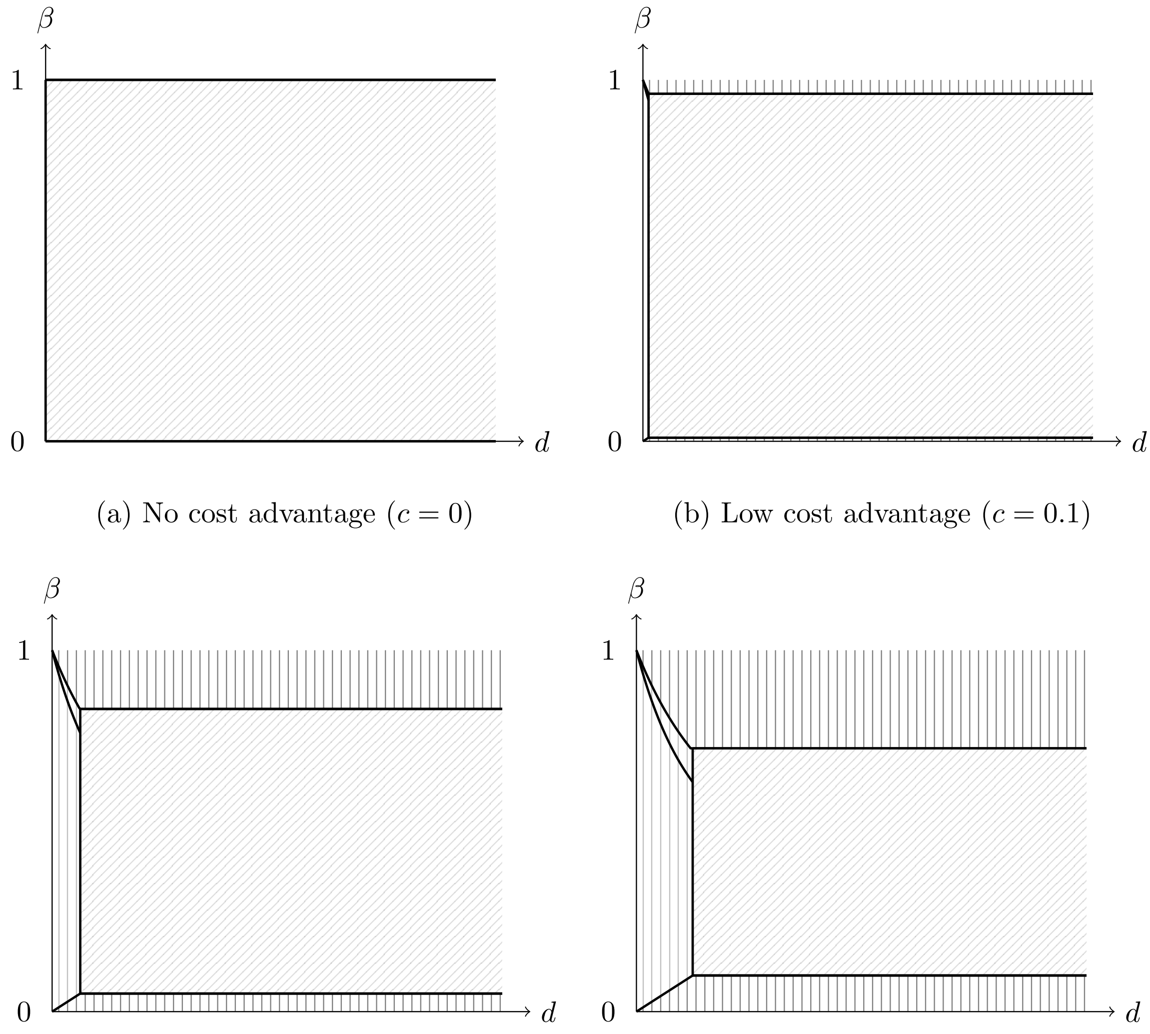
For low β, the results are equivalent to the above. However, if demand uncertainty is high, firms use technology A to produce their inventory, which they sell in both demand states. In the low-demand state, they sell it at a price of zero. A monopolist produces $\bar{q}_A^* = a/2(1-\beta)$; competitive firms produce $\bar{q}_i^* = a/3(1-\beta)$.

Figure 3 illustrates when firms with the combined technology produce an additional quantity after the demand has materialized, i.e., actually use technology S. The decision of a monopolist coincides with the competitive firms' decision. For $d \geq c$, firms offer the entire inventory in the low-demand state at a price of zero if $\beta \geq (a^2 + 2c^2)/(a^2 + 4ac)$. For $d < c$, firms may dispose of some quantity if demand uncertainty is low. A monopolist does not discard and sells the entire inventory if $\beta \geq (a^2 + 2d^2)/(a^2 + 4ad)$. For competitive firms, there may exist multiple equilibria for $\beta \in [((2a+3d)(4a+3d) - 12a\sqrt{d(a+2d)})/((4a+3d)^2 + 12ad), (a^2 - ad + 4d^2)/(a^2 + 5ad - 2d^2)]$: One in which firms dispose of in the low-demand state, and one in which firms produce larger inventories and sell it at a price of zero in the low-demand state. In the latter, firms have a higher expected profit. Note that the upper bound is larger than the monopolist's threshold since $d < c \leq a/2$.

Consequently, firms do not forgo an early production cost advantage for sufficiently large demand uncertainty if the demand becomes perfectly elastic.

[19] The kink at a price of zero is, to some extent, arbitrary. Note that if consumers also incurred a disposal cost, the demand would be $P_\vartheta(Q) = \max\{a - b_\vartheta Q, -d\}$ and our results do not change.

[20] We also analyzed the model with distinct technologies, and the results are similar.



(a) No cost advantage ($c = 0$)

(b) Low cost advantage ($c = 0.1$)

(c) Medium cost advantage ($c = 0.5$)

(d) High cost advantage ($c = 1$)

Figure 3: In the diagonally gray (vetically black) shaded area, both firms (do not) use technology S. (Demand intercept $a = 10$ and the abscissa is truncated at 8.)

Similar as in Ferreira (2006), there exists another kind of equilibrium. Each firm produces inventory $\bar{q}_i^* \geq a/(1-\beta)$, resulting in a price of zero in both demand states. Firms make a profit of zero. This equilibrium only exists since the marginal cost of production in stage 1 is normalized to zero, which is exactly the same point at which demand becomes perfectly elastic. If the demand function becomes perfectly elastic at a price below the marginal cost of production, firms would make losses with such a strategy.

Observable Inventories. In reality, firms may not perfectly observe their competitors' inventories. Public companies, however, announce their targeted sales to inform investors. Those announcements may help the competitor to infer the inventory.[21] Thus, in this section, we assume that competitors observe each other's inventories be-

[21]Doyle and Snyder (1999) study U.S. car makers' announcements of production plans and show how they affect market outcomes. Thus, the announcements are informative and not mere cheap talk.

fore choosing their sales volumes. We have analyzed both cases, where firms choose between either technology A or S, as in Section 3, or have access to both technologies simultaneously. The formal derivation of both is relegated to the web appendix.

If inventories are observable, an additional effect comes into play. With a higher disposal cost, firms sell large parts of their inventories even if demand is lower than expected. An extensive inventory, therefore, implies a large intended sales volume. A firm can only credibly commit to selling its total inventory if the disposal is expensive.

Generally, the disposal cost reduces inventories, yet, the neglected effect works in the opposite direction. If firms have the combined technology and observe their competitor's inventory, the equilibrium may not be unique, nor is it monotone, due to the opposing effects. Although firms are ex-ante symmetric, there may exist asymmetric equilibria, where one firm (she) has a larger inventory than the other. The firm with the smaller inventory (he) produces additional quantities if demand is higher than expected, while the other disposes of parts of her inventory if demand is lower than expected. Expected disposal decreases with its cost. Furthermore, inventories still decrease with the disposal cost. Due to the lower trade volume, consumer surplus decreases, too.

When firms have a single production technology, the outcome in the symmetric subgames does not change either. In the (S, S) subgame, firms simultaneously produce after the demand's realization, i.e., without an inventory that could be observed. In the (A, A) subgame, it turns out that the outcome is also equivalent, because firms have correct expectations of the inventory. However, the outcome in the asymmetric subgame changes. Like in the setup with the combined technology, the first mover disposes of parts of her inventory if demand is below its expectation. Her expected inventory and disposal decreases with d and so does the expected consumer surplus.

However, for a high disposal cost, she does not dispose of anything. Increasing d allows her to commit to selling a larger inventory credibly. Therefore, her inventory goes up, and the expected sales volume increases, resulting in a higher expected consumer surplus.

A regulatory increase in the disposal cost fulfills its purpose of decreasing the quantity disposed of in all considered setups. However, in almost all cases, this comes at a cost for consumers. Competition for market shares is not achieved by this policy, even if inventories are observable.

The firm producing (more) in the first stage is negatively affected by an increase in the disposal cost, because any reaction to new information about demand becomes more costly. By contrast, observability strengthens her dominant position in terms of market shares. She can signify large targeted sales with a large inventory. The costlier disposal, the less does a firm disposes of its inventory. The inventory's credibility to indicate targeted sales increases with d, strengthening the firm's competitive advantage.

Her expected profit is, thus, ambiguously affected by an increase in the disposal cost. Precisely, her expected profit is U-shaped.

The other firm manufactures (large parts of) his production after the demand's realization. Accordingly, he has an information advantage, which is more valuable if the other firm's reaction to new information is costly. His expected profit, thus, increases with d.[22]

To sum up, the increased credibility benefits the first mover if demand is lower than expected, while the information advantage benefits the second mover if demand is higher than expected. By contrast to unobserved inventories, both firms' expected profits may increase simultaneously with the disposal cost.

H&M and Zara[23], the two most prominent players in the European fashion market, increased their recycling standards over the last years. According to our setup, this leads to higher costs, which may increase profits. Our model is consistent with the market structure: H&M mainly produces in Asia and ships its product to the European market; Zara manufactures mostly in Europe. Zara manufactures close to the market. The firm claims that within two weeks of the original design, clothes are in retail. The shipment from Asia to Europe already takes more time. Consequently, H&M's clothes are manufactured earlier. In the fast fashion industry, multiple products are introduced in a single week to stay on-trend. In order to compete trendily, according to our model, H&M produces large parts of its inventory abroad and thus has a larger expected disposal than Zara. This is consistent with the fact that Zara only discards 10% of its products, which is half of the industry average.

With the exception of the asymmetric equilibrium in the combined technology setup discussed above, there always exists the same symmetric equilibrium described in Proposition 5.[24] The difference between observable and unobservable inventories is, therefore, the asymmetric equilibrium's existence. We use numerical simulations to compare the equilibria and find that both firms' expected profits may be higher in the symmetric equilibrium. Note that the firms can guarantee to be in the symmetric equilibrium if inventories are unobservable. However, there exist parameters where one firm, either she or he, expects a higher profit in an asymmetric equilibrium, i.e., prefers it if inventories are observable.

Perfect Competition. New firms may enter a profitable market in the long run, resulting in a perfectly competitive market. Firms make zero expected profits. A higher disposal cost decreases the firms' inventories and expected consumer surplus:

[22] If firms have distinct production technologies, the second mover's expected profit decreases for $d \geq (a+c)(1+5\beta)/2(5+\beta)$. The first mover does not discard and can credibly sell a large inventory, resulting in a lower expected profit for the second mover.

[23] Zara is part of the Inditex holding, which also includes Pull&Bear, Massimo Dutti, Oysho, and others. Although we mean Inditex in lieu, we refer to Zara because it is the flagship of Inditex.

[24] Dubey and Shubik (1981) show generally that any pure strategy equilibrium with unobservable inventories is also an equilibrium if inventories are observed.

Suppose there are many firms using technology A and many using technology S, thus expected profits are zero. Firms with technology A may dispose of parts of their inventory if demand is below expectations, i.e., incur a cost. Therefore, they have to turn a positive profit if demand is above expectations. An increase in the disposal cost forces those firms to decrease their inventory. Otherwise, firms turn a negative expected profit because the loss in the low-demand state outweighs the gains in the high state. Due to the lower inventory, firms with technology S increase their production, but these quantities come at a higher production cost. Introducing an additional cost in an efficient market decreases consumer surplus.

Price Competition. Instead of quantity competition in the second stage, Kreps and Scheinkman (1983) and Montez and Schutz (2021) use price competition. Both firms choosing technology S results in zero profits à la Bertrand. Both choosing technology A results in a model similar to de Frutos and Fabra (2011): firms end up with different capacity/inventory levels. Given an asymmetric technology choice, the first mover has to set prices weakly below the second mover's marginal cost, or else the latter undercuts the price. It depends on the rationing rule how demand is shared with equal prices. For example, one could use equal demand sharing as de Frutos and Fabra (2011). If her inventory is not large enough to satisfy total demand, he becomes a monopolist for the residual demand. He sets the price strictly above his marginal cost, and she tries to undercut it. No pure strategy equilibrium may exist.

5 Conclusion

For each unit not sold, firms incur a cost if their inventory is not fully reversible. An unsold unit is not only a loss in revenue, but it also causes additional costs. As we show in this paper, firms discard less of their commodities if the disposal cost increases. Accordingly, one would expect consumer surplus to increase and firms' expected profits to decrease.

Although correct, this expectation is shortsighted. Firms adjust their inventories if the disposal cost goes up. The higher the disposal cost, the costlier it is for a firm to adjust to demand below expectations, i.e., a low disposal cost substitutes information about demand. To mitigate costs, a firm lowers its inventory, which leads to a lower profit if high demand materializes.

In our model, a monopolist either produces its inventory earlier, at a low cost and with little information about demand, or later, with more information yet at a higher cost. The firm forgoes the early production cost advantage if and only if the disposal cost and demand uncertainty are both simultaneously high. Expected consumer surplus and the expected profit go down with the disposal cost.

We derive similar results for competing firms. Although firms are ex-ante symmetric, they may choose asymmetric production strategies. We derive three necessary conditions for an asymmetric equilibrium: First, early production has to yield a strict cost advantage. Second, the marginal cost to dispose of has to be higher than the cost advantage from early production. Third, demand has to be uncertain, yet, not to a too large extent. If demand uncertainty is considerable, firms jointly produce with more information, yet at a higher cost. If demand uncertainty is low, both firms produce at a low cost.

We show that a regulatory increase in the disposal cost decreases the expected disposal. Yet, consumers do not benefit from fiercer competition for market sales; the lower trade volume impairs them. In general, consumers suffer from a higher disposal cost. However, one exception exists: In an asymmetric equilibrium, the firm manufacturing with more information has monopoly power over the residual demand. When the disposal cost increases, the competitor may postpone its production, firms become equal and competition increases, benefiting consumers.

Generally, firms expect a lower profit, the costlier disposal is. However, there are also some exceptions. With an increase in the disposal cost, information about demand becomes more valuable because disposing of products as a response to demand below expectations becomes costlier. Firms may, therefore, postpone their production with an increasing disposal cost, and these changes in the timing of production may benefit a firm. Furthermore, in the asymmetric equilibrium, one of the two firms has an information advantage. Since costlier disposal increases the information's value, the firm expects a higher profit.

None of these exceptions exist if firms have a combination of both production technologies, allowing them to either produce additional quantities after the demand has materialized or to dispose of some quantities. The unique equilibrium is symmetric, and firms only use the production technology after demand has materialized if the disposal cost and demand uncertainty are both simultaneously high.

Our result on forgoing the early production cost advantage hinges to some extent on demand being not perfectly elastic. If demand becomes perfect elastic for large quantities, firms have an additional channel to dispose of their products by offering them at a zero price. Thus, if demand uncertainty is high, firms end up offering their entire production for free if demand is lower than expected.

Moreover, we discuss the case of firms observing their competitor's inventory. This gives rise to another effect: a firm's inventory sends the message of its intended sales. However, a company can only credibly commit to selling large parts of its inventory if the disposal is costly. Due to this opposing effect, each firm's profit may simultaneously increase with the disposal cost. Firms may profitably agree on costlier disposal, e.g., in the form of higher recycling standards. Expected disposal decreases, yet consumer surplus does, too.

Our model is consistent with the market structure in the fashion market and its pattern of the discarded quantity. Furthermore, our model explains the 'reshoring' of firms. If the cost advantage abroad declines or recycling standards increase, i.e., the disposal cost goes up, information about demand becomes more valuable. Thus, firms produce closer to their home market.

We study demand uncertainty. However, in some markets, demand is relatively predictable, but costs may vary due to input factor prices. Commodities that are expensive in production are discarded less often. Studying cost uncertainty may, therefore, be of interest.[25] Another interesting question is how the disposal cost affects collusive behavior. Paha (2017) studies collusion with capacities; Rotemberg and Saloner (1989) study the use of inventory for strategic collusion. US data of the aluminum industry analyzed in Rosenbaum (1989) reveals that markups are negatively correlated with inventory but positively correlated with excess capacity. A low disposal cost allows a firm to inexpensively adjust its sales volume, making it easier to deviate and potentially aggravating strategic collusion.

[25]In Thille (2006), the prediction of the model crucially depends on the primary uncertainty. Less competitive market structures have a relatively low price variance when uncertainty is primarily due to uncertain cost, and relatively high price variance when uncertainty is mainly due to uncertain demand.

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A Appendix

Perfectly Elastic Demand. In this section, we present the monopolistic setup from Section 2, yet modify the demand function such that it becomes perfectly elastic at a price of zero. Formally, $P_\vartheta(Q) = \max\{a - b_\vartheta Q, 0\}$.

For a monopolist using technology S, there is no difference. However, if it uses technology A, the firm now has the option to insure a zero profit by offering $q_{A,\vartheta} \geq a/b_\vartheta$. If the firm discards, it makes a profit of $\pi_{A,\vartheta} = (a+d)^2/4b_\vartheta - d\bar{q}_A$, which is negative if $\bar{q}_A > (a+d)^2/4db_\vartheta$. Since $a/b_\vartheta < (a+d)^2/4db_\vartheta \Leftrightarrow (a-d)^2 > 0$, the monopolist can avoid losses by selling its entire inventory. The optimal sales volume is thus

$$q_{A,\vartheta}(\bar{q}_A) = \begin{cases} \bar{q}_A, & \text{if } \bar{q}_A \leq \frac{a+d}{2b_\vartheta}; \\ \frac{a+d}{2b_\vartheta}, & \text{if } \frac{a+d}{2b_\vartheta} < \bar{q}_A \leq \frac{a+d}{2d}\frac{a+d}{2b_\vartheta}; \\ \bar{q}_A, & \text{if } \bar{q}_A > \frac{a+d}{2d}\frac{a+d}{2b_\vartheta}. \end{cases}$$

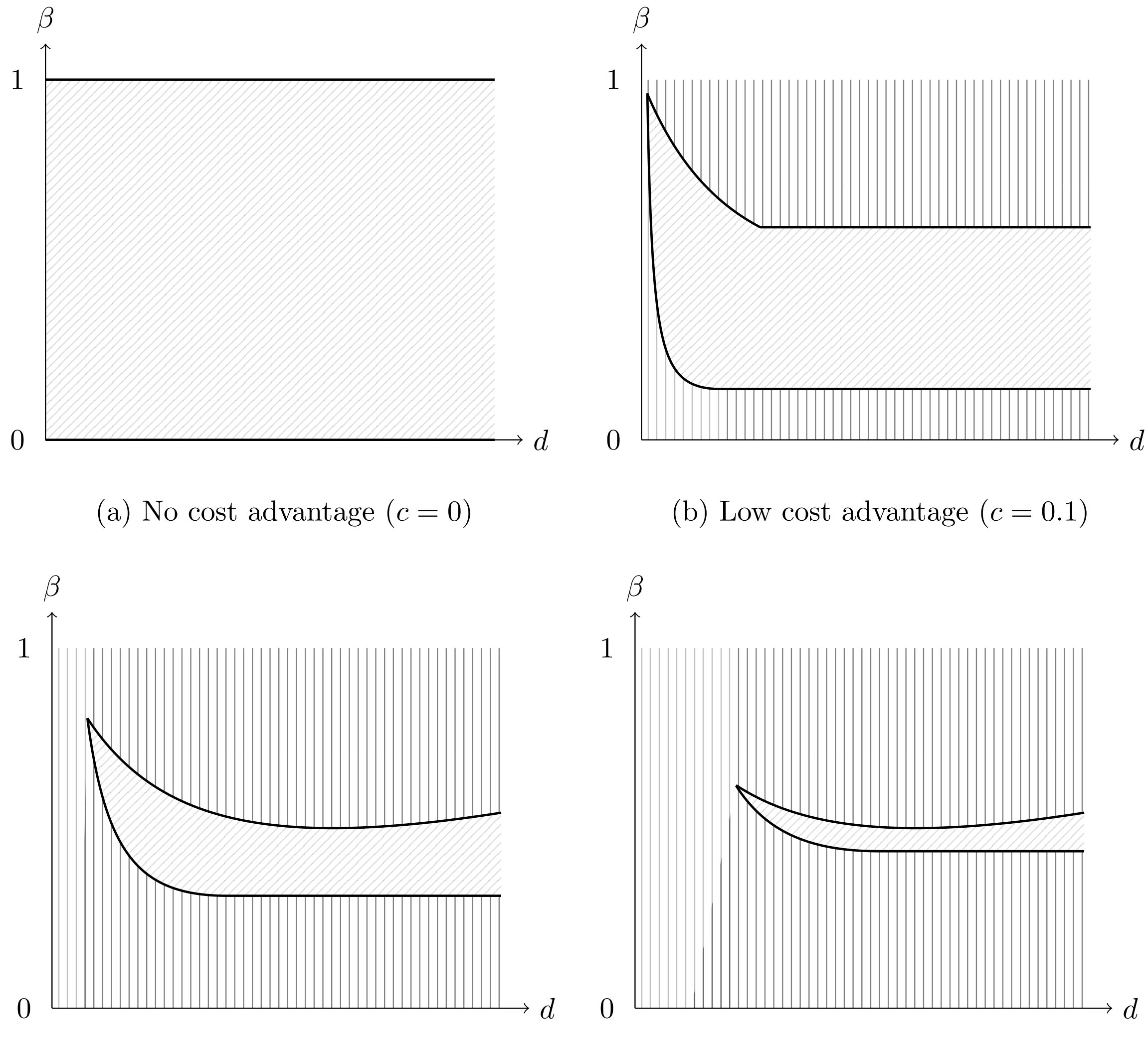
The firm should produce an inventory that it can sell at a positive profit in the high-demand state, i.e., it should not dispose of anything in the high-demand state. If it does, or the price is zero in the high-demand state, the firm is better of with a lower inventory. Thus, three possibilities arise. (i) sell the entire inventory in the low-demand state at a positive profit, (ii) dispose of parts of it in the low-demand state and make a positive profit, and (iii) offer the entire inventory, which results in a price of zero in the low-demand state.

The three candidates for the profit-maximizing inventory are (i) $\bar{q}_A = a/2$, (ii) $\bar{q}_A = (a-d)/2(1-\beta)$, and (iii) $\bar{q}_A = a/2(1-\beta)$. This results in an expected profit of (i) $\mathbb{E}[\pi_A] = a^2/4$, (ii) $\mathbb{E}[\pi_A] = (a^2 - 2\beta ad + d^2)/4(1-\beta^2)$, and (iii) $\mathbb{E}[\pi_A] = a^2/8(1-\beta)$.

By comparing the expected profits, we get that (i) is maximal if $d \geq \beta a$ and $\beta \leq 1/2$. Moreover, the condition in stage two is $d \geq \beta a$. (ii) yields the highest expected profit if $d \leq \beta a$ and $\beta \leq (a^2 + 2d^2)/(a^2 + 4ad)$. Additionally, the second stage requires $d \leq \beta a$ and $\beta \leq (a^2 + 3d^2)/(a^2 + 4ad - d^2)$. Note that the last condition is implied by the condition on the expected profit. For (iii) to be profit maximizing, it is necessary that $\beta \geq 1/2$ and $\beta \geq (a^2 + 2d^2)/(a^2 + 4ad)$. Moreover, the second stage requires $\beta > (a^2 + d^2)/(a^2 + 4ad + d^2)$, which is again satisfied by the condition on the profit. Accordingly, the expected profit with technology A is

$$\mathbb{E}[\pi_A^*] = \begin{cases} \frac{a^2}{4}, & \text{if } \beta < \min\left\{\frac{d}{a}, \frac{1}{2}\right\}; \\ \frac{(a+d)^2}{8(1+\beta)} + \frac{(a-d)^2}{8(1-\beta)}, & \text{if } \beta \in \left(\frac{d}{a}, \frac{a^2+2d^2}{a^2+4ad}\right]; \\ \frac{a^2}{8(1-\beta)}, & \text{if } \beta \geq \max\left\{\frac{a^2+2d^2}{a^2+4ad}, \frac{1}{2}\right\}. \end{cases}$$

Finally, we compare the expected profit from technology A and S:
If $\beta < \min\left\{d/a, 1/2, \sqrt{2ac - c^2}/a\right\}$, the firm produces in the first stage and sells its total inventory at a positive price in both demand states. If
$\beta \in \left(d/a, \max\left\{(a^2 + 2d^2)/(a^2 + 4ad), (2ac - c^2 + d^2)/2ad\right\}\right]$, the firm again produces with technology A and sells its total inventory in the high-demand state yet disposes of parts of it in



(a) No cost advantage ($c = 0$) (b) Low cost advantage ($c = 0.1$)

(c) Medium cost advantage ($c = 0.5$) (d) High cost advantage ($c = 1$)

Figure 4: In the vetically black (diagonally gray) shaded area, the monopoly uses technology A (S). (Demand intercept $a = 10$ and the abscissa is truncated at 8.)

the low-demand state. If $\beta \geq \max\left\{(a^2 + 2d^2)/(a^2 + 4ad), 1/2, (a^2 - 4ac + 2c^2)/a^2\right\}$, the firm still produces in the first stage and offers its total inventory in both demand states, resulting in a zero price if demand is below expectations. Otherwise, the firm prefers technology S and produces in the second stage. Figure 4 illustrates the parameter regions. For a high demand uncertainty, the firm does not forgo an early production cost advantage.

Demand Uncertainty. In the main text, we assume a demand function with an uncertain slope. This simplifies the analysis in the duopoly model. Here, we show that our results for a monopolist do not change if we use a random intercept instead of random slope in the demand function. Formally, let the demand function in state $\vartheta \in \{l, h\}$ be $P_\vartheta(Q) = a_\vartheta - bQ$, with $a_l = 1 - \alpha$ and $a_h = 1 + \alpha$, such that $\alpha \in [0, 1)$ measures the demand uncertainty. Both states are equally likely. The rest of the setup is unchanged: the firm either chooses technology A or S, and the timing follows the illustration in Figure 1. For simplicity, we assume $c \leq 1 - \alpha$ to guarantee trade.

First, suppose the monopolist produces with technology A. In the second stage, the production cost is sunk and the inventory is fixed. The monopolist offers $q_{A,\vartheta} = \min\{(a_\vartheta + d)/2b, \bar{q}_A\}$ on the market. If $d \geq \alpha$, the monopolist produces an inventory of $\bar{q}_A^* = 1/2b$, which it sells regardless of the demand's realization. Otherwise, it produces $\bar{q}_A^* = (1 + \alpha - d)/2b$, which it sells in the high-demand state. It disposes of $\bar{q}_A^* - q_{A,l}^* = (\alpha - d)/b$ if demand is below expectations. Accordingly, the expected profit is $\mathbb{E}[\pi_A^*] = 1/4b$ if $d \geq \alpha$ and $\mathbb{E}[\pi_A^*] = ((1 - \alpha + d)^2 + (1 + \alpha - d)^2)/8b = (1 + d^2 + \alpha^2 - 2d\alpha)/4b$, if $\alpha > d$. Note that the expected profit weakly decreases with d; so do expected disposal and expected consumer surplus $\mathbb{E}[CS_A^*] = \mathbb{E}[\pi_A^*]/2$.

Next, suppose the monopolist produces with technology S. It produces $q_{S,\vartheta}^* = (a_\vartheta - c)/2b$ and makes an expected profit of $\mathbb{E}[\pi_S^*] = ((1 - \alpha - c)^2 + (1 + \alpha - c)^2)/8b$. By comparing the expected profits we get the monopolist's optimal technology choice. It chooses technology S if and only if

$$\alpha \geq \begin{cases} \frac{2c - c^2 + d^2}{2d}, & \text{if } d < \sqrt{c(2-c)}; \\ \sqrt{c(2-c)}, & \text{if } d \geq \sqrt{c(2-c)}. \end{cases}$$

Equivalent to Section 2, the threshold is larger than 1 if $d \leq c$. Thus, the monopolist only forgoes an early production cost advantage if the disposal cost and demand uncertainty are both simultaneously high.

B Proofs

This section contains all relegated proofs of lemmas and propositions and derives the best responses (6), (15), and (16).

Proof Equation (6). Firm i sells its inventory at least in one state, else the firm could increase its profit by adjusting its inventory. Suppose the firms sells its inventory in both states, implying the optimal inventory $\bar{q}_i = a/2 - (1+\beta)q_{j,l}/4 - (1-\beta)q_{j,h}/4$. The firm indeed sells the entire inventory in the low-demand state if $q_{j,h} - q_{j,l} \geq 2(\beta a - d)/(1 - \beta^2)$ and in the high-demand state if $q_{j,h} - q_{j,l} \leq 2(\beta a + d)/(1 - \beta^2)$.

Next, suppose the firm sells its inventory in the high-demand state and disposes of parts of it in the low-demand state. This implies an optimal inventory $\bar{q}_i = (a-d)/2(1-\beta) - q_{j,h}/2$. Obviously, it has no incentive to discard in the high-demand state; in the low-demand state, the firm does dispose of parts of its inventory if $q_{j,h} - q_{j,l} \leq 2(\beta a - d)/(1 - \beta^2)$.

Finally, suppose it offers its entire inventory in the low-demand state and disposes of parts of it in the high-demand state, resulting in the optimal inventory $\bar{q}_i = (a-d)/2(1+\beta) - q_{j,l}/2$. Again, it is obvious that it offers the entire inventory in the low-demand state; in the high-demand state, the firm only disposes of if $q_{j,h} - q_{j,l} \geq 2(\beta a + d)/(1 - \beta^2)$.

This proves the best response function (6). Note that the best response is unique even if firm j uses a mixed strategy: Suppose firm j mixes between different sales volumes and plays

$q_{j,\vartheta}$ with probability $\rho_\vartheta(q_{j,\vartheta})$. Firm i's expected profit is

$$\begin{aligned}\mathbb{E}[\pi_{A,i,\vartheta}] =&\frac{1}{2}\int_0^\infty \rho_h(q_{j,h})[(a-(1-\beta)(q_{i,h}+q_{j,h}))q_{i,h} - d(\bar{q}_i - q_{i,h})]\mathrm{d}q_{j,h} + \\ &\frac{1}{2}\int_0^\infty \rho_l(q_{j,l})[(a-(1+\beta)(q_{i,l}+q_{j,l}))q_{i,l} - d(\bar{q}_i - q_{i,l})]\mathrm{d}q_{j,l} \\ =&\frac{1}{2}[(a-(1-\beta)(q_{i,h}+\mathbb{E}[q_{j,h}]))q_{i,h} - d(\bar{q}_i - q_{i,h})] + \\ &\frac{1}{2}[(a-(1+\beta)(q_{i,l}+\mathbb{E}[q_{j,l}]))q_{i,l} - d(\bar{q}_i - q_{i,l})].\end{aligned}$$

Thus, there is always a unique best response. □

Proof Lemma 1. We prove that there exists a unique equilibrium. Therefore, we look for fixpoints of the best response function of (5) and (6).

First, we show that $\bar{q}_i = 0$ is never an equilibrium strategy. Suppose firm i has produced inventory $\bar{q}_i = 0$. Firm j's best response to $q_{i,\vartheta} = 0$ is the inventory $\bar{q}_j = \max\{(a-d)/2(1-\beta), a/2\}$ and sales volume $q_{j,\vartheta} = \min\{(a+d)/2b_\vartheta, \bar{q}_j\} \Rightarrow q_{j,\vartheta} \leq (a+d)/2b_\vartheta$, implying a strictly positive price. Firm i's optimal response is $q_{i,\vartheta} = \min\{(a+d)/2b_\vartheta - q_{j,\vartheta}/2, \bar{q}_i\}$. Thus, if $\bar{q}_i \leq (a+d)/4(1+\beta)$, the firm could sell its entire inventory in both states. Note that the price stays positive for $\bar{q}_i \leq (a-d)/2b_\vartheta$. Hence, firm i could make a strictly positive profit by deviating to a strictly positive inventory.

There remain three best response candidates to form an equilibrium, presented in Table 6, resulting in nine equilibrium candidates.

(i)	$\bar{q}_i = \frac{2a-(1+\beta)q_{j,l}-(1-\beta)q_{j,h}}{4}$	$q_{i,l} = \bar{q}_i$	$q_{i,h} = \bar{q}_i$
(ii)	$\bar{q}_i = \frac{a-d-(1-\beta)q_{j,h}}{2(1-\beta)}$	$q_{i,l} = \frac{a+d}{2(1+\beta)} - \frac{q_{j,l}}{2}$	$q_{i,h} = \bar{q}_i$
(iii)	$\bar{q}_i = \frac{a-d-(1+\beta)q_{j,l}}{2(1+\beta)}$	$q_{i,l} = \bar{q}_i$	$q_{i,h} = \frac{a+d}{2(1-\beta)} - \frac{q_{j,h}}{2}$

Table 6: Equilibrium Candidates

First, we show that no asymmetric equilibrium exists. Suppose firm j uses (i) and firm i uses (ii), resulting in the unique solution $\bar{q}_i = (2a+\beta a-3d)/6(1-\beta)$ and $\bar{q}_j = a/3$. Firm j should not dispose of any inventory in the low state, formally, $(a+d)/2(1+\beta) - q_{i,l}/2 \geq q_{j,l} \Leftrightarrow d \geq \beta a$. However, firm i discards in the low-demand state, i.e., $q_{i,l} < \bar{q}_i \Leftrightarrow \beta a > d$, resulting in a contradiction.

Next, suppose firm j still plays (i), yet firm i plays (iii). The unique solution is $\bar{q}_i = (2a-\beta a-3d)/6(1+\beta)$ and $\bar{q}_j = a/3$. Moreover, $q_{i,h} = (2a+\beta a+3d)/6(1-\beta)$. If firm i discards in the high state, $q_{i,h} \leq \bar{q}_i \Leftrightarrow (\beta a+d)/(1-\beta^2) \leq 0$, yielding a contradiction.

Next, suppose firm j plays (ii) and firm i still plays (iii). The unique solution is $\bar{q}_i = (a-3d)/(1+\beta)$ and $\bar{q}_j = (a-3d)/(1-\beta)$. Moreover, $q_{i,h} = (a+3d)/3(1-\beta)$. If firm i discards in the high state, $q_{i,h} \leq \bar{q}_i \Leftrightarrow (2\beta a+6d)/3(1-\beta^2) \leq 0$, also yielding a contradiction.

Thus, no asymmetric equilibrium exists. Both firms using (i) results in the symmetric equilibrium $\bar{q}_i = a/3$. This indeed forms an equilibrium if firms do not dispose of anything, formally, $\beta a \leq d$.

Both firms playing (ii) results in the symmetric equilibrium $\bar{q}_i = (a-d)/3(1-\beta)$. The disposal behavior is optimal if $\beta a \geq d$.

Finally, both firms playing (iii) results in $\bar{q}_i = (a-d)/3(1+\beta)$ and $q_{i,h} = (a+d)/3(1-\beta)$. However, $\bar{q}_i > q_{i,h} \Leftrightarrow \beta a + d < 0$, yielding a contradiction.

Since a firm's best response is always a singleton, there is no equilibrium in mixed strategies. Hence, the equilibrium is unique. Plugging in the sales volume yields the expected expressions in Lemma 1. Since $\beta \in [0,1)$, the negative effect of d has a higher weight than the positive. Thus, d's negative effect follows directly. □

Proof Lemma 2. Firms know the state of demand and maximize (2). Note that similar as in Lemma 1, $q_{i,\vartheta} = 0$ is never an equilibrium. Therefore, best response functions are linear and strictly decreasing in the relevant part, resulting in a unique equilibrium. Exploiting the symmetry directly implies $q^*_{S,\vartheta} = (a-c)/3b_\vartheta$. Plugging in the sales volume yields the desired result. □

Proof Lemma 3. The first mover's best response function is given by (6), the second mover's by (8). Like in the proof of Lemma 1, we analyze the best response function step by step to find all equilibria.

Suppose $\bar{q}_1 = 0$, directly implying $q_{1,h} = q_{1,l} = 0$ and thus $q_{2,\vartheta} = (a-c)/2b_\vartheta$. This results in $P_\vartheta = (a+c)/2$, thus, firm 1 can get a strictly positive profit by deviating to a small, yet strictly positive inventory. Hence there is no equilibrium with zero inventory.

Next, suppose $q_{2,\vartheta} = 0$, resulting in $\bar{q}_i \in \{a/2, (a-d)/2(1-\beta), (a-d)/2(1+\beta)\}$, given by Table 6. Moreover, $P_\vartheta \in \{a/2, (a+d)/2, (a-d)/2\}$. The minimal price $(a-d)/2 \geq c$ by our assumption $a \geq 2c + d$, i.e., firm 2 is active in both states unless the inequality binds. Accordingly, his best response is strictly positive, i.e., $q_{2,\vartheta} = (a-c)/2b_\vartheta - q_{1,\vartheta}/2$.

There remain three cases for an equilibrium. Suppose firm 1 uses (i) in Table 6, yielding $\bar{q}_1 = (a+c)/3$. Firm 1 does not dispose of any inventory if $\beta(a+c)/2 \leq d$, i.e., this forms an equilibrium.

Next, suppose firm 1 uses (ii) in Table 6. This results in $\bar{q}_1 = (a-2d+c)/3(1-\beta)$, and firm 1 does indeed discard in the low-demand state if $\beta(a+c)/2 > d$.

Finally, suppose firm 1 uses (iii) in Table 6, resulting in $\bar{q}_1 = (a-2d+c)/3(1+\beta)$. However, $q_{1,h} \geq q_{1,l} \Leftrightarrow \beta a + c + 2d \leq 0$ contradicting that the firm discards in the high-demand state.

No other equilibria exist, because they would not be on the firms' best response functions. Therefore, the equilibrium is unique. Plugging in the sales volumes directly yields the expected expressions. As in the proof of Lemma 1, d's effect follows directly. □

Proof Proposition 3. First, we show that for $\beta \geq \beta_S(d)$ both firms choose technology S, i.e., $\mathbb{E}[\pi^*_S] \geq \mathbb{E}[\pi^*_1]$, where the expressions are given by (9) and (10). First, for $d < \beta(a+c)/2$ the inequality can be rearranged to $\beta d(a+c) \geq ac + d^2$. Hence, the first part of $\beta_S(d)$

directly follows. Note that the left-hand side increases more strongly in d than the right-hand side, since $d \leq \beta(a+c)$. By definition, the first part of $\beta_S(d)$ therefore decreases. For $d \geq \beta(a+c)/2$, the inequality simplifies to $\beta^2(a+c)^2 \geq 4ac$.

Second, we show that for $\beta \leq \beta_A(d)$ both firms choose technology A, i.e., $\mathbb{E}[\pi_A^*] \geq \mathbb{E}[\pi_2^*]$, given by (7) and (12). Note that $\beta a \geq \beta(a+c)/2$. For $d < \beta(a+c)/2$, the inequality simplifies to $\beta d \leq c$, which concludes the first part of $\beta_A(d)$. This decreases with d. For $d \in [\beta(a+c)/2, \beta a]$, the inequality can be written as $\beta^2(a+c)(5a-7c)+8\beta ad-16c(a-c)-4d^2 \leq 0$. The left-hand side is convex and at $\beta = 0$ negative and increasing. Hence, the larger root is the relevant one, which is explicitly given in the second part of $\beta_A(d)$.

We use the implicit function theorem to show $\beta_A(d)$'s second part has a negative slope. The derivative of the left-hand side with respect to d is $8(\beta a - d) > 0$; the derivative with respect to β is $2\beta(a+c)(5a-7c) + 8ad \geq 0$. Hence, the implicit function theorem implies that $\beta_A(d)$ decreases.

For $d \geq \beta a$, the inequality simplifies to $\beta^2(9a^2 - 2ac - 7c^2) \leq 16c(a-c)$, implying the third part of $\beta_A(d)$.

It remains to show that $\beta_A(d) \leq \beta_S(d)$ to prove that the equilibrium is unique in pure strategies. This inequality is proven in the next proposition's proof. □

Proof Proposition 4. We first compare the first and second movers' profits. She expects a larger profit if and only if $\mathbb{E}[\pi_1^*] \geq \mathbb{E}[\pi_2^*]$, where the expressions are given in (10) and (12). Equating the two expressions and rearranging yields

$$\beta_{AS}(d) = \begin{cases} \frac{2ac-c^2+d^2}{2ad}, & \text{if } d < \beta\frac{a+c}{2}; \\ \sqrt{\frac{4c(2a-c)}{(3a-c)(a+c)}}, & \text{if } d \geq \beta\frac{a+c}{2}. \end{cases}$$

Thus, $\beta < \beta_{AS}(d)$ implies $\mathbb{E}[\pi_1^*] > \mathbb{E}[\pi_2^*]$ and $\beta > \beta_{AS}(d)$ implies $\mathbb{E}[\pi_1^*] < \mathbb{E}[\pi_2^*]$.

Next, we show that $\beta_A(d) < \beta_{AS}(d) < \beta_S(d)$. Note that all thresholds are above 1 for $d \leq c$. Thus, we can focus on $d > c$. By definition, at $\beta_A(d)$, $\mathbb{E}[\pi_A^*] = \mathbb{E}[\pi_2^*]$ and by the inequality above $\mathbb{E}[\pi_1^*] > \mathbb{E}[\pi_2^*]$. Similarly, at $\beta_S(d)$ by definition $\mathbb{E}[\pi_S^*] = \mathbb{E}[\pi_1^*]$ and by the inequality above $\mathbb{E}[\pi_2^*] > \mathbb{E}[\pi_1^*]$. Thus, the first mover's profit increases discontinuously at $\beta_A(d)$ while the second mover's profit decreases discontinuously at $\beta_S(d)$.

For $d < \beta(a+c)/2$, the two inequalities above can be simplified to $2ac^2 < ac^2 - c^3 + ad^2 + cd^2 < 2ad^2$. The two inequalities can be rewritten as $(a+c)(d^2-c^2) > 0$ and $(a-c)(c^2-d^2) < 0$, which both are satisfied for $d > c$.

Since $\beta_S(d)$ and $\beta_{AS}(d)$ are continuous and constant while $\beta_A(d)$ decreases continuously for $d \geq \beta(a+c)/2$, the relevant inequality is satisfied. This directly concludes the proof for the firms' part.

For the consumer surplus, we show a discontinuous decrease at $\beta = \beta_A(d)$ and, subsequently, we prove a discontinuous increase at $\beta = \beta_S(d)$.

Formally, at $\beta = \beta_A(d)$, $\mathbb{E}[CS_A^*] > \mathbb{E}[CS_{AS}^*]$, where the expressions are given in Lemma 1 and Equation (11):

First consider $d \leq \beta(a+c)/2$, thus, we can rewrite $\mathbb{E}[CS_A^*] = (2a-2d)^2/36(1-\beta) + (2a+2d)^2/36(1+\beta)$, which is obviously strictly larger than $\mathbb{E}[CS_{AS}^*]$ for $d \leq c$. For $d > c$, we can simplify the inequality $\mathbb{E}[CS_A^*] > \mathbb{E}[CS_{AS}^*] \Leftrightarrow \beta < (4ac - c^2 + 3d^2)/2d(2a+c)$. Since $\beta_A(d) = c/d < (4ac - c^2 + 3d^2)/2d(2a+c) \Leftrightarrow c < d$, consumer surplus increases discontinuously at $\beta = \beta_A(d)$ for $d \leq \beta(a+c)/2$.

Next, for $d \in (\beta(a+c)/2, \beta a)$, we can rewrite $\mathbb{E}[CS_A^*] > \mathbb{E}[CS_{AS}^*] \Leftrightarrow 0 > -16ac - 16d^2 + 4c^2 + 32\beta ad - \beta^2(a+c)(7a-5c)$. Note that at $\beta_A(d)$ we have $0 = -16ac + 16c^2 - 4d^2 + 8\beta ad + \beta^2(a+c)(5a-7c)$, from the last proposition's proof. Subtracting this from the inequality yields the condition $0 \geq -(c^2+d^2) + 2\beta ad - \beta^2(a^2-c^2) = -(\beta a - d)^2 - (1-\beta^2)c^2$. Hence, the condition is satisfied at $\beta_A(d)$.

Finally, let us consider the case $d \geq \beta a$.
We can simplify $\mathbb{E}[CS_A^*] > \mathbb{E}[CS_{AS}^*] \Leftrightarrow \beta < 2\sqrt{c(4a-c)}/\sqrt{9a^2 - 2ac + 5c^2}$, which can be compared to $\beta_A(d) = 2\sqrt{c(4a-4c)}/\sqrt{9a^2 - 2ac - 7c^2}$. Note that $\beta_A(d)$ is lower than $2\sqrt{c(4a-c)}/\sqrt{9a^2 - 2ac + 5c^2} \Leftrightarrow 27c(a-c)^2 > 0$, for $c > 0$.

For the second part, we show that at $\beta = \beta_S(d)$, $\mathbb{E}[CS_S^*] > \mathbb{E}[CS_{AS}^*]$, where the expressions are given in Lemma 2 and Equation (11). For $d \leq \beta(a+c)/2$, the inequality simplifies to $4\beta d(2a-c) > 2(4ac - 3c^2 + d^2)$. Plugging in $\beta_S(d)$, we can simplify the expression to $(d^2 - c^2)(a-c) > 0$. $d > c$ is a necessary condition for the threshold function $\beta_S(d)$, to be strictly below 1. Since both expected consumer surplus functions are continuous and constant for $d \geq \beta(a+c)/2$, this concludes the proof for the consumer surplus.

It remains to prove that the expected disposal decreases in its cost. First, note that in the $(S,\, S)$ subgame, expected disposal is always zero. Next, using Lemmas 1 and 3, we can compare the expected disposal: For $d \leq \beta(a+c)/2$ we get $2\mathbb{E}[\bar{q}_A^* - q_A^*] > \mathbb{E}[\bar{q}_1^* - q_1^*] \Leftrightarrow 2\beta a - 2d > \beta(a+c) - 2d \Leftrightarrow a > c$. For $d \geq \beta(a+c)/2$, $\mathbb{E}[\bar{q}_1^* - q_1^*] = 0$, while $2\mathbb{E}[\bar{q}_A^* - q_A^*]$ is positive, yet decreases until it reaches zero at $d = \beta a$. This concludes the proof. □

Proof Equations (15) and (16). We use $\bar{q}_i$ if the sales volume equals the inventory and else $\hat{q}_i$. To simplify notation, let $\tau_1 := (a-c)/2(1+\beta) - q_{j,l}/2$, $\tau_2 := (a+d)/2(1+\beta) - q_{j,l}/2$, $\tau_3 := (a-c)/2(1-\beta) - q_{j,h}/2$, and $\tau_4 := (a+d)/2(1-\beta) - q_{j,h}/2$.

With this, the expected profit can be written as

$$\mathbb{E}[\pi_i] = \begin{cases} \frac{1}{2}(a-(1-\beta)(\bar{q}_i+q_{j,h}))\bar{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\bar{q}_i+q_{j,l}))\bar{q}_i, & \text{if } \max\{\tau_1,\tau_3\} \leq \bar{q}_i < \min\{\tau_2,\tau_4\}; \\ \frac{1}{2}(a-(1-\beta)(\bar{q}_i+q_{j,h}))\bar{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\hat{q}_i+q_{j,l})+d)\hat{q}_i - \frac{1}{2}d\bar{q}_i, & \text{if } \max\{\tau_2,\tau_3\} \leq \bar{q}_i < \tau_4; \\ \frac{1}{2}(a-(1-\beta)(\hat{q}_i+q_{j,h})-c)\hat{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\bar{q}_i+q_{j,l}))\bar{q}_i + \frac{1}{2}c\bar{q}_i, & \text{if } \tau_1 < \bar{q}_i < \min\{\tau_2,\tau_3\}; \\ \frac{1}{2}(a-(1-\beta)(\hat{q}_i+q_{j,h})+d)\hat{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\bar{q}_i+q_{j,l}))\bar{q}_i - \frac{1}{2}d\bar{q}_i, & \text{if } \max\{\tau_1,\tau_4\} \leq \bar{q}_i < \tau_2; \\ \frac{1}{2}(a-(1-\beta)(\bar{q}_i+q_{j,h}))\bar{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\hat{q}_i+q_{j,l})-c)\hat{q}_i + \frac{1}{2}c\bar{q}_i, & \text{if } \tau_3 \leq \bar{q}_i < \min\{\tau_1,\tau_4\}; \\ \frac{1}{2}[(a-(1-\beta)(\hat{q}_i+q_{j,h}))\hat{q}_i - \\ \max\{d(\bar{q}_i-\hat{q}_i), c(\hat{q}_i-\bar{q}_i\}] + \\ \frac{1}{2}[(a-(1+\beta)(\hat{q}_i+q_{j,l}))\hat{q}_i - \\ \max\{d(\bar{q}_i-\hat{q}_i), c(\hat{q}_i-\bar{q}_i\}], & \text{else.} \end{cases}$$

In the first part, firm i sells its inventory in both states, yielding the interior solution $\bar{q}_i = a/2 - (1+\beta)q_{j,l}/4 + (1-\beta)q_{j,h}/4$. In the second part, firm i discards if demand is below expectations, yielding the interior solution $\bar{q}_i = (a-d)/2(1-\beta) - q_{j,h}/2$. In the third part, firm i produces additional quantities if demand is above expectations, yielding the interior solution $\bar{q}_i = (a+c)/2(1+\beta) - q_{j,l}/2$. The fourth part implies an interior solution of $\bar{q}_i = (a-d)/2(1+\beta) - q_{j,l}/2$ and the fifth of $\bar{q}_i = (a+c)/2(1-\beta) - q_{j,h}/2$.

The last part strictly increases or decreases, depending on c and d. For $c = d$, multiple maxima may exist where a firm does not have to sell its inventory in either of the two states. However, all result in the same sales volume and expected profit as if the firm produced an inventory to sell entirely in at least one state.

Plugging in the interior solutions to their respective intervals results in the best response functions given in (15) and (16).

By the same argument as in the proof of Equation (6), the best response is the same to any mixed strategy of player j. □

Proof Proposition 5. By the same argument as in the proof of Lemma 1, firm i has a strictly positive inventory. Assume first that $c \neq d$. The best reply candidates for an equilibrium are thus given in Table 7.

First, we show that no asymmetric equilibrium exists. Note that (i)-(iii) are the same as in Table 6; thus, we get the same contradiction for an asymmetric equilibrium.

Suppose firm i plays (iv) and firm j (i). The unique solution implies $\bar{q}_i = (2a - \beta a + 3c)/6(1+\beta)$ and $\bar{q}_j = a/3$. We get $q_{i,h} - q_{i,l} = (\beta a - c)/(1-\beta^2)$, which implies $\beta a \geq c$.

(i)	$\bar{q}_i = \frac{2a-(1+\beta)q_{j,l}-(1-\beta)q_{j,h}}{4}$	$q_{i,l} = \bar{q}_i$	$q_{i,h} = \bar{q}_i$
(ii)	$\bar{q}_i = \frac{a-d-(1-\beta)q_{j,h}}{2(1-\beta)}$	$q_{i,l} = \frac{a+d}{2(1+\beta)} - \frac{q_{j,l}}{2}$	$q_{i,h} = \bar{q}_i$
(iii)	$\bar{q}_i = \frac{a-d-(1+\beta)q_{j,l}}{2(1+\beta)}$	$q_{i,l} = \bar{q}_i$	$q_{i,h} = \frac{a+d}{2(1-\beta)} - \frac{q_{j,h}}{2}$
(iv)	$\bar{q}_i = \frac{a+c-(1+\beta)q_{j,l}}{2(1+\beta)}$	$q_{i,l} = \bar{q}_i$	$q_{i,h} = \frac{a-c}{2(1-\beta)} - \frac{q_{j,h}}{2}$
(v)	$\bar{q}_i = \frac{a+c-(1-\beta)q_{j,h}}{2(1-\beta)}$	$q_{i,l} = \frac{a-c}{2(1+\beta)} - \frac{q_{j,l}}{2}$	$q_{i,h} = \bar{q}_i$

Table 7: Equilibrium candidates

However, firm j's strategy implies $(a-c)/2(1-\beta) - q_{i,h}/2 < \bar{q}_j \Leftrightarrow \beta a < c$, resulting in a contradiction.

Next, suppose firm i chooses (iv) and firm j uses (ii). The unique solution implies $\bar{q}_i = (a{+}2c{-}d)/3(1+\beta)$ and $\bar{q}_j = (a{+}c{-}2d)/3(1-\beta)$. A necessary condition for firm j to produce no additional quantities in the high-demand state is $(a-c)/2(1-\beta) - q_{i,h}/2 < \bar{q}_j \Leftrightarrow d < c$. However, a necessary condition for firm i to not dispose of any inventory in the low-demand state is $(a+d)/2(1+\beta) - q_{j,l}/2 \geq \bar{q}_i \Leftrightarrow c \leq d$, resulting in a contradiction.

Next, suppose firm i uses (iv) and firm j uses (iii). The unique solution implies $\bar{q}_i = (a+2c+d)/3(1+\beta)$ and $\bar{q}_j = (a-c-2d)/3(1+\beta)$. Given the strategy, firm j discards in the high-demand state. However, $q_{j,h} = (a+c+2d)/3(1-\beta) > \bar{q}_j$, i.e., a contradiction.

Next, suppose firm i uses (v) and firm j uses (i). The unique solution implies $\bar{q}_i = (2a+\beta a+3c)/6(1-\beta)$ and $\bar{q}_j = a/3$. Firm i produces in the low state, yet $q_{i,l} = (2a-\beta a-3c)/6(1+\beta) \leq (2a+\beta a+3c)/6(1-\beta) = q_{i,h}$, yielding a contradiction.

Next, suppose firm i plays (v) and firm j (ii). The unique solution implies $\bar{q}_i = (a+2c+d)/3(1-\beta)$ and $\bar{q}_j = (a-c-2d)/3(1-\beta)$. In the low-demand state, firm i produces $q_{i,l} = (a-2c-d)/3(1+\beta) < \bar{q}_i$, yielding a contradiction.

Next, suppose firm i uses (v) and j uses (iii). In order for (iii) to be optimal, it is necessary that $q_{i,h} > q_{i,l}$. However, this directly contradicts (v).

Finally, suppose firm i plays (v) and firm j (iv). The unique solution implies $\bar{q}_i = (a+2\beta a+3\beta c)/3(1-\beta^2)$ and $\bar{q}_j = (a+3c)/3(1+\beta)$. Firm i produces in the low state, yet $q_{i,l} = (a-3c)/3(1+\beta) \leq \bar{q}_i$, i.e., a contradiction.

The remaining candidates are the symmetric ones. We have already shown that (iii) does not form a symmetric equilibrium. Similarly, if both firms play (v), $\bar{q}_i = (a+c)/3(1-\beta)$. They produce an additional quantity to sell $q_{i,l} = (a-c)/3(1+\beta)$ in the low-demand state. However, $q_{i,l} < \bar{q}_i$, i.e., a contradiction.

Both playing (i) implies the symmetric equilibrium $\bar{q}_i = a/3$. Neither of the firms produce or dispose of inventory in any state if $\beta a \leq \min\{c, d\}$. Similarly, both playing (ii) implies $\bar{q}_i = (a-d)/3(1-\beta)$, which forms an equilibrium if $d < \min\{\beta a, c\}$. Finally, both playing (iv) results in $\bar{q}_i = (a+c)/3(1+\beta)$, which is an equilibrium if $c < \min\{\beta a, d\}$.

It remains to analyze the case where $c = d$. There may exist multiple equilibria, which only differ in the inventory. Suppose both firms produce inventory $\bar{q}_i \in [(a+c)/2(1+\beta) -$

$q_{j,l}/2, (a-d)/2(1-\beta) - q_{j,h}/2]$, which implies sales volumes $q_{i,h} = (a-c)/2(1-\beta) - q_{j,h}/2$ and $q_{i,l} = (a+c)/2(1+\beta) - q_{j,l}/2$. Symmetry directly implies $q_{i,h} = (a-c)/3(1-\beta)$ and $q_{i,l} = (a+c)/3(1+\beta)$. This forms an equilibrium if $q_{i,h} - q_{i,l} < 2(\beta a - c)(1-\beta^2) \Leftrightarrow \beta a > c$. The outcome is thus the same as if the firms sold their entire inventory in one state.

Plugging in the sales volumes yields the expected values. The disposal cost's negative effect immediately follows. □

C Web Appendix

Mixed Equilibrium. In this section, we discuss the unique symmetric equilibirum of the model presented in Section 3. There, we have shown that the equilibrium is unique and symmetric whenever both firms choose the same technology, i.e., whenever (A, A) or (S, S) forms an equilibrium.[26] Whenever the asymmetric equilibirum exists, a second asymmetric equilibrium exists with the firms' labels interchanged. Consequently, there also exists a symmetric equilibrium in mixed strategies, where firms play S with probability

$$p = \frac{\mathbb{E}[\pi_2^*] - \mathbb{E}[\pi_A^*]}{\mathbb{E}[\pi_2^*] - \mathbb{E}[\pi_A^*] + \mathbb{E}[\pi_1^*] - \mathbb{E}[\pi_S^*]},$$

and play A with $1-p$. Taking the derivative with respect to d yields

$$\frac{\partial p}{\partial d} = \frac{\frac{\partial \mathbb{E}[\pi_1^*]}{\partial d}(\mathbb{E}[\pi_A^*] - \mathbb{E}[\pi_2^*]) + \left(\frac{\partial \mathbb{E}[\pi_2^*]}{\partial d} - \frac{\partial \mathbb{E}[\pi_A^*]}{\partial d}\right)(\mathbb{E}[\pi_1^*] - \mathbb{E}[\pi_S^*])}{(\mathbb{E}[\pi_2^*] - \mathbb{E}[\pi_A^*] + \mathbb{E}[\pi_1^*] - \mathbb{E}[\pi_S^*])^2} \geq 0.$$

The mixed equilibrium only exists if $\mathbb{E}[\pi_A^*] \leq \mathbb{E}[\pi_2^*]$ and $\mathbb{E}[\pi_S^*] \leq \mathbb{E}[\pi_1^*]$, thus, the sign follows from Lemmas 1-3. Note that p is continuous in d and the derivative exists everywhere except at $d = \beta(a+c)/2$ and $d = \beta a$. The probability of playing strategy S, thereby, increases with d.

A firm's expected profit in this mixed equilibrium can be written as

$$\mathbb{E}[\pi_M] = p^2\mathbb{E}[\pi_S^*] + p(1-p)(\mathbb{E}[\pi_1^*] + \mathbb{E}[\pi_2^*]) + (1-p)^2\mathbb{E}[\pi_A^*].$$

Consequently,

$$\begin{aligned} \frac{\partial \mathbb{E}[\pi_M]}{\partial d} &= 2p\frac{\partial p}{\partial d}\mathbb{E}[\pi_S^*] + (1-2p)\frac{\partial p}{\partial d}(\mathbb{E}[\pi_1^*] + \mathbb{E}[\pi_2^*]) + \\ & \quad p(1-p)\left(\frac{\partial \mathbb{E}[\pi_1^*]}{\partial d} + \frac{\partial \mathbb{E}[\pi_2^*]}{\partial d}\right) + (1-p)^2\frac{\partial \mathbb{E}[\pi_A^*]}{\partial d} - 2(1-p)\frac{\partial p}{\partial d}\mathbb{E}[\pi_A^*]. \end{aligned}$$

For $\beta \to \beta_S(d)^-$, players more often use S, formally, $p \to 1^-$. The second row goes to zero and the first simplifies to $\partial p/\partial d(2\mathbb{E}[\pi_S^*] - \mathbb{E}[\pi_1^*] - \mathbb{E}[\pi_2^*]) = \partial p/\partial d(\mathbb{E}[\pi_S^*] - \mathbb{E}[\pi_2^*]) \leq 0$, which follows from the definition of $\beta_S(d)$ and Proposition 3. A firm's expected profit decreases if the disposal cost goes up.

[26] See Proposition 3 for details.

For $\beta \to \beta_A(d)^+$, expected profits are ambiguous. Formally, $p \to 0^+$, $\mathbb{E}[\pi_2^*] \to \mathbb{E}[\pi_A^*]^+$, and $\mathbb{E}[\pi_1^*] \geq \mathbb{E}[\pi_A^*]$, which implies

$$\frac{\partial \mathbb{E}[\pi_M]}{\partial d} \to \frac{\partial \mathbb{E}[\pi_A^*]}{\partial d} + \frac{\mathbb{E}[\pi_1^*] - \mathbb{E}[\pi_A^*]}{\mathbb{E}[\pi_1^*] - \mathbb{E}[\pi_S^*]}(\frac{\partial \mathbb{E}[\pi_2^*]}{\partial d} - \frac{\partial \mathbb{E}[\pi_A^*]}{\partial d}).$$

For $d \in (\beta(a+c)/2, \beta a)$, we have $\partial \mathbb{E}[\pi_2^*]/\partial d = 0$ while $\partial \mathbb{E}[\pi_A^*]/\partial d \leq 0$, resulting in a decreasing profit if $\mathbb{E}[\pi_S^*] \leq \mathbb{E}[\pi_A^*]$. For example, let $a = 1$, $c = 1/10$, $d = 3/10$, and $\beta \approx 0.413318 \approx \beta_A(d)$, implying $\mathbb{E}[\pi_S^*] \approx 0.109$ and $\mathbb{E}[\pi_A^*] \approx 0.113$.

However, the expected profit may also increase: Let $a = 1$, $c = 1/5$, $d = 3/10$, and $\beta = 2/3 = \beta_A(d)$. This implies $\partial \mathbb{E}[\pi_M]/\partial d = 13/75 > 0$.

In contrast to the main text, the expected profit is continuous if we focus on the symmetric equilibrium in mixed strategies instead of a pure strategy equilibrium. Yet, the effects discussed in the main text are mixed, resulting in the non-monotonic expected profit.

N Firms. Here we extend the model from Section 4 with the combined technology to N symmetric firms. Let us first repeat the setup. Each firm produces inventory $\bar{q}_i$ at a zero marginal cost. After the demand has materialized, firms choose their sales volume q_i. On the one hand, if the sales volume exceeds the firm's inventory, the additional quantity induces a marginal cost of $c \geq 0$. On the other hand, if a firm's sales volume is lower than its inventory, the quantity disposed of induces a marginal cost of $d > 0$. Formally, a firm's profit is

$$\mathbb{E}[\pi(q_i, \bar{q}_i)] = \mathbb{E}[P_\vartheta(Q)q_i - c\max\{(q_i - \bar{q}_i, 0\} - d\max\{(\bar{q}_i - q_i, 0\}],$$

where the inverse demand is $P_\vartheta(Q) = a - b_\vartheta(Q)$. The intercept $a > 2c + d$ is common knowledge, while the slope b_ϑ takes on the value $b_l = 1 + \beta$ or $b_h = 1 - \beta$, each with equal probability. Q is the total sales volume, i.e., the sum of q_i over all N.

As in the main text, we assume that firms do not observe their competitors' inventories. In the second stage, a firm takes its own inventory as given and chooses $q_i \geq 0$ to maximize

$$\pi(q_i|\bar{q}_i) = P_\vartheta(Q)q_i - c\max\{(q_i - \bar{q}_i, 0\} - d\max\{(\bar{q}_i - q_i, 0\}.$$

The best response function can be derived as in the main text and written as

$$q_i(Q_{-i}|\bar{q}_i) = \max\left\{\min\left\{\max\left\{\frac{a+d}{2b_\vartheta} - \frac{1}{2}Q_{-i}, 0\right\}, \bar{q}_i\right\}, \frac{a-c}{2b_\vartheta} - \frac{1}{2}Q_{-i}\right\},$$

where $Q_{-i} = \sum_{j\neq i} q_j$ is the other firms' sales volumes. Since firms compete with a homogeneous product, it does not matter for firm i how Q_{-i} is composed. By the same argument, we immediately get the optimal inventory, for $d < c$ this is

$$\bar{q}_i(Q_{-i,l}, Q_{-i,h}) = \begin{cases} \frac{a-d}{2(1-\beta)} - \frac{1}{2}Q_{-i,h}, & \text{if } Q_{-i,h} - Q_{-i,l} \leq \frac{2(\beta a - d)}{1-\beta^2}; \\ \frac{a}{2} - \frac{(1+\beta)}{4}Q_{-i,l} - \frac{(1-\beta)}{4}Q_{-i,h}, & \text{if } \frac{2(\beta a - d)}{1-\beta^2} \leq Q_{-i,h} - Q_{-i,l} \leq \frac{2(\beta a + d)}{1-\beta^2}; \\ \frac{a-d}{2(1+\beta)} - \frac{1}{2}Q_{-i,l}, & \text{if } Q_{-i,h} - Q_{-i,l} \geq \frac{2(\beta a + d)}{1-\beta^2}, \end{cases}$$

q_i^*	high demand	low demand
$d < \min\{\beta a, c\}$	$\frac{a-d}{(N+1)(1-\beta)}$	$\frac{a+d}{(N+1)(1+\beta)}$
$\beta a \leq \min\{c, d\}$	$\frac{a}{(N+1)}$	$\frac{a}{(N+1)}$
$c < \min\{\beta a, d\}$	$\frac{a-c}{(N+1)(1-\beta)}$	$\frac{a+c}{(N+1)(1+\beta)}$

Table 8: N-firms' inventory and sales volume with combined technologies. Inventory equals the sales volume in the high (low) demand state if $d < \min\{\beta a, c\}$ ($c < \min\{\beta a, d\}$).

and for $c < d$ it is

$$\bar{q}_i(Q_{-i,l}, Q_{-i,h}) = \begin{cases} \frac{a+c}{2(1+\beta)} - \frac{1}{2}Q_{-i,l}, & \text{if } Q_{-i,h} - Q_{-i,l} \leq \frac{2(\beta a - c)}{1-\beta^2}; \\ \frac{a}{2} - \frac{(1+\beta)}{4}Q_{-i,l} - \frac{(1-\beta)}{4}Q_{-i,h}, & \text{if } \frac{2(\beta a - c)}{1-\beta^2} \leq Q_{-i,h} - Q_{-i,l} \leq \frac{2(\beta a + c)}{1-\beta^2}; \\ \frac{a+c}{2(1-\beta)} - \frac{1}{2}Q_{-i,h}, & \text{if } Q_{-i,h} - Q_{-i,l} \geq \frac{2(\beta a + c)}{1-\beta^2}, \end{cases}$$

whenever it is positive, resulting in the symmetric equilibrium summarized in Table 8.

Comparing Table 8 with Table 5 in the main text shows that the equilibrium is similar and thus the results in Proposition 5 remain valid for any number of firms. However, an interesting trade-off for policymakers arises: Suppose $d < \min\{\beta a, c\}$, thus, firms discard if demand materializes below their expectations. Expected consumer surplus can be written as

$$\mathbb{E}[CS^*] = \left(\frac{N}{2(N+1)}\right)^2 \left(\frac{(a-d)^2}{1-\beta} + \frac{(a+d)^2}{1+\beta}\right).$$

This increases with the number of firms, $N/(N+1) < (N+1)/(N+2) \Leftrightarrow N^2 + 2N < N^2 + 2N + 1$, which generally results from increased competition. The expected disposal, however, also increases in the number of firms. Formally,

$$N\mathbb{E}[(\bar{q}_i^* - q_i^*)] = \frac{N}{(N+1)} \frac{\beta a - d}{(1-\beta^2)}.$$

By the same argument as above, expected disposal goes up with the number of firms. A decrease in the disposal cost reduces the quantity disposed of, as in the main text, moreover even more strongly the more competitors are active in the market.

In this setup, increasing competition due to the number of firms benefits consumers, yet increases the disposal. Policymakers concerned about the discarded quantities, therefore, face a trade-off.

Suppose firms face a fixed cost, such that there exists an upper bound on N where firms expect a positive profit. Let's denote the fix cost by F. Thus, a firm expects the profit

$$\mathbb{E}[\pi_i^*] = \frac{1}{2(N+1)^2} \left(\frac{(a-d)^2}{1-\beta} + \frac{(a+d)^2}{1+\beta}\right) - F.$$

Increasing the disposal cost lowers this profit. Consequently, the upper bound on N goes down, and some firms leave the market. This results in less competition and a lower consumer surplus; firms may benefit from fewer competitors. Generally, consumers are worse off if disposal is costly due to the lower production volume and, additionally, because firms' market power may increase.

Observable Inventories. Here, we formally derive the results discussed in Section 4.

Distinct Technologies. The game proceeds as follows. First, both firms choose their production technology A or S simultaneously. Firms with technology A produce inventory $\bar{q}_i \geq 0$ at zero marginal cost before the demand materializes. After the demand's realization, they can sell at most their production volume, $q_i \leq \bar{q}_i$, yet have to pay a marginal cost $d > 0$ to dispose of the residual quantity. Firms using technology S produce after the demand has materialized at a marginal cost $c \geq 0$. By contrast to the model in Section 3, we assume that competitors can observe each other's inventories.

Let us first analyze the symmetric subgames. Suppose both firms choose technology A. When demand materializes, the production cost is sunk and firms maximize their profits, yielding the best reply (5). Without loss of generality, let $\bar{q}_i \geq \bar{q}_j$.

Lemma 4. *The unique subgame equilibrium is*

$$\begin{array}{lll} q_i = \bar{q}_i, & q_j = \bar{q}_j, & \text{if } \bar{q}_j < \frac{a+d}{b_\vartheta} - 2\bar{q}_i \ ; \\ q_i = \frac{a+d}{2b_\vartheta} - \frac{1}{2}q_j, & q_j = \bar{q}_j, & \text{if } \frac{a+d}{b_\vartheta} - 2\bar{q}_i \leq \bar{q}_j \leq \frac{a+d}{3b_\vartheta} \ ; \\ q_i = \frac{a+d}{3b_\vartheta}, & q_j = \frac{a+d}{3b_\vartheta}, & \text{if } \bar{q}_j \geq \frac{a+d}{3b_\vartheta}. \end{array}$$

Accordingly, the firm with the larger inventory first starts discarding if demand is below expectations. However, note that it still sells a larger quantity than its competitor.[27] Moreover, the sales volume is always higher in the high-demand state.[28] Accordingly, firm i produces an inventory that it can sell entirely in the high-demand state. Otherwise, it would increase its expected profit by lowering its production in order to mitigate disposal costs. By the same argument, firm j also produces an inventory that is entirely sold in the high-demand state.

Firm i's expected profit is

$$\mathbb{E}[\pi_i] = \begin{cases} (a - (\bar{q}_i + \bar{q}_j))\bar{q}_i, & \text{if } \bar{q}_i \leq \frac{a+d}{2(1+\beta)} - \frac{1}{2}\bar{q}_j; \\ \frac{1}{2}(a - (1-\beta)(\bar{q}_i + \bar{q}_j) + d)\bar{q}_i + & \\ \frac{1}{2}(a - (1+\beta)(\hat{q}_i + q_{j,l}) + d)\hat{q}_i - d\bar{q}_i, & \text{if } \bar{q}_i \geq \frac{a+d}{2(1+\beta)} - \frac{1}{2}\bar{q}_j, \end{cases}$$

where $\hat{q}_i$ does not depend on $\bar{q}_i$, and $q_{j,l}$ is firm j's sales volume in the low-demand state. Formally, for the optimal inventory it does not matter if firm j offers its entire inventory or less, since firm i discards anyways. Firm i's best response function is $\bar{q}_i(\bar{q}_j) = \max\{(a - \bar{q}_j)/2, (a-d)/2(1-\beta) - \bar{q}_j/2\}$.

[27] Formally, $(a+d)/(2b_\vartheta) \geq \bar{q}_j/2 \Leftrightarrow \bar{q}_j \leq (a+d)/b_\vartheta$, which is implied by $\bar{q}_j \leq (a+d)/3b_\vartheta$.

[28] Formally, $q_{j,h} - q_{j,l}$ is either 0 or $2(a+d)/3(1-\beta^2)$, and $q_{i,h} \geq q_{i,l} \Leftrightarrow 2(a+d)/(1-\beta^2) \geq q_{j,h} - q_{j,l}$.

Taking into account that firm i never produces more than $(a+d)/2(1-\beta)-\bar{q}_j/2$, we can write firm j's expected profit as

$$\mathbb{E}[\pi_j] = \begin{cases} (a-(\bar{q}_i+\bar{q}_j))\bar{q}_j, & \text{if } \bar{q}_j < \frac{a+d}{1+\beta} - 2\bar{q}_i; \\ \frac{1}{2}(a-(1-\beta)(\bar{q}_i+\bar{q}_j))\bar{q}_j + & \\ \frac{1}{2}(a-(1+\beta)(\frac{a+d}{2(1+\beta)}+\frac{\bar{q}_j}{2}))\bar{q}_j, & \text{if } \frac{a+d}{1+\beta} - 2\bar{q}_i \le \bar{q}_j \le \min\{\frac{a+d}{3(1+\beta)}, \frac{a+d}{1-\beta} - 2\bar{q}_i\}, \\ \frac{1}{2}(a-(1-\beta)(\bar{q}_i+\bar{q}_j)+d)\bar{q}_j + & \\ \frac{1}{2}(a-(1+\beta)(\hat{q}_i+\hat{q}_j)+d)\hat{q}_j - d\bar{q}_j, & \text{if } \frac{a+d}{3(1+\beta)} \le \bar{q}_j \le \frac{a+d}{1-\beta} - 2\bar{q}_i. \end{cases}$$

This yields three candidates for an interior solution. (i) $\bar{q}_j = (a-\bar{q}_i)/2$, (ii) $\bar{q}_j = (3a-d)/2(3-\beta) - \bar{q}_i(1-\beta)/(3-\beta)$, and (iii) $\bar{q}_j = (a-d)/2(1-\beta) - \bar{q}_i/2$.

Let us first focus on (ii). In this case, firm i's best response is $\bar{q}_i = (a-d)/2(1-\beta)-\bar{q}_j/2$, implying the equilibrium candidate $\bar{q}_i = (3a-5d+\beta a+\beta d)/2(5-\beta)(1-\beta)$ and $\bar{q}_j = 2a/(5-\beta)$. A necessary condition is $\bar{q}_j \le (a+d)/3(1+\beta) \Leftrightarrow 7\beta a + a + \beta d - 5d \le 0$, yet firm i's best response implies $\beta a > d$, resulting in a contradiction. Hence, candidate (ii) never forms an equilibrium.

The remaining cases imply the unique symmetric equilibrium $\bar{q}_i = \bar{q}_j = \max\{(a-d)/3(1-\beta), a/3\}$, which is equivalent to the case when inventories are not observable. Therefore, the equilibrium outcome is equivalent to Lemma 1.

When both firms choose technology S, the game is the same as in the main text. The unique subgame equilibrium is described by Lemma 2. This concludes the analysis of the symmetric subgames.

Now suppose one firm (she) uses technology A, while the other (he) uses technology S. As in the main text, we index the first by 1 and the second by 2. For firm 1, production is sunk when she chooses her sales volume resulting in the best reply given by (5). Firm 2 produces after the demand has materialized; his best response function is given by (8). The two functions imply a unique subgame equilibrium for the sales volumes.

Lemma 5. *If $d \le a-2c$, the unique subgame equilibrium is*

$$\begin{array}{lll} q_1 = \bar{q}_1, & q_2 = \frac{a-c}{2b_\vartheta} - \frac{1}{2}\bar{q}_1, & \textit{if } \bar{q}_1 < \frac{a+2d+c}{3b_\vartheta}\ ; \\ q_1 = \frac{a+2d+c}{3b_\vartheta}, & q_2 = \frac{a-d-2c}{3b_\vartheta}, & \textit{if } \bar{q}_1 \ge \frac{a+2d+c}{3b_\vartheta}. \end{array}$$

If $d > a-2c$, the unique subgame equilibrium is

$$\begin{array}{lll} q_1 = \bar{q}_1, & q_2 = \frac{a-c}{2b_\vartheta} - \frac{1}{2}\bar{q}_1, & \textit{if } \bar{q}_1 < \frac{a-c}{b_\vartheta}\ ; \\ q_1 = \bar{q}_1, & q_2 = 0, & \textit{if } \frac{a-c}{b_\vartheta} \le \bar{q}_1 \le \frac{a+d}{2b_\vartheta}\ ; \\ q_1 = \frac{a+d}{2b_\vartheta}, & q_2 = 0, & \textit{if } \bar{q}_1 \ge \frac{a+d}{2b_\vartheta}. \end{array}$$

This directly reveals why we impose our assumption $a \ge d+2c$: the first firm cannot block the second.

The first mover produces an inventory that she can sell entirely in the high-demand state; otherwise she could mitigate her disposal costs by lowering the production. We can thus write

q_1^*	$d < t_1$	$t_1 \leq d < t_2$	$t_2 \leq d < t_3$	$t_3 \leq d$
high demand	$\frac{a+2d+c}{3(1-\beta)}$	$\frac{a-2d+c}{2(1-\beta)}$	$\frac{a+2d+c}{3(1+\beta)}$	$\frac{a+c}{2}$
low demand	$\frac{a+2d+c}{3(1+\beta)}$	$\frac{a+2d+c}{3(1+\beta)}$	$\frac{a+2d+c}{3(1+\beta)}$	$\frac{a+c}{2}$

Table 9: First mover's inventory and sales volume with observable inventory. Inventory equals the sales volume in the high-demand state.

q_2^*	$d < t_1$	$t_1 \leq d < t_2$	$t_2 \leq d < t_3$	$t_3 \leq d$
high demand	$\frac{a-d-2c}{3(1-\beta)}$	$\frac{a+2d-3c}{4(1-\beta)}$	$\frac{a-c}{2(1-\beta)} - \frac{a+2d+c}{6(1+\beta)}$	$\frac{a-c}{2(1-\beta)} - \frac{a+c}{4}$
low demand	$\frac{a-d-2c}{3(1+\beta)}$	$\frac{a-d-2c}{3(1+\beta)}$	$\frac{a-d-2c}{3(1+\beta)}$	$\frac{a-c}{2(1+\beta)} - \frac{a+c}{4}$

Table 10: Second mover's sales volume with observable inventory.

her expected profit as

$$\mathbb{E}[\pi_1] = \begin{cases} (\frac{a+c}{2} - \frac{1}{2}\bar{q}_1)\bar{q}_1, & \text{if } \bar{q}_1 \leq \frac{a+2d+c}{3(1+\beta)}; \\ \frac{1}{2}(\frac{a+c}{2} - (1-\beta)\frac{1}{2}\bar{q}_1)\bar{q}_1 + & \\ \frac{1}{2}(a - (1+\beta)(\hat{q}_1 + \hat{q}_2))\hat{q}_1 - \frac{1}{2}d(\bar{q}_1 - \hat{q}_1), & \text{if } \frac{a+2d+c}{3(1+\beta)} \leq \bar{q}_1 \leq \frac{a+2d+c}{3(1-\beta)}. \end{cases}$$

Her profit maximizing production volume is

$$\bar{q}_1^* = \begin{cases} \frac{a+2d+c}{3(1-\beta)}, & \text{if } d < t_1; \\ \frac{a-2d+c}{2(1-\beta)}, & \text{if } t_1 \leq d < t_2; \\ \frac{a+2d+c}{3(1+\beta)}, & \text{if } t_2 \leq d < t_3; \\ \frac{a+c}{2}, & \text{if } d \geq t_3, \end{cases}$$

where $t_1 := (a+c)/10$, $t_2 := (a+c)(1+5\beta)/2(5+\beta)$, and $t_3 := (a+c)(1+3\beta)/4$. By our assumption $a \geq d + 2c$, the thresholds are ranked $t_1 \leq t_2 \leq t_3$. For $d < t_3$, the firm disposes of parts of her inventory if demand is lower than expected.

Table 9 summarizes the first mover's inventory and sales volumes. The inventory is non-monotonic with the disposal cost. Note that the sales volume in the low-demand state is constant for $d < t_3$.

The second mover's sales volume is summarized in Table 10. By the best response, the second mover's sales volume goes in the opposite direction with d compared to the first mover's. His sales volume in the low-demand state also stays constant for $d < t_3$.

Due to the inventory's observability, the equilibrium in the asymmetric subgame is different to the main text. We characterize its outcome in the following Lemma.

Lemma 6. *In the* (A, S) *and* (S, A) *games' unique subgame perfect equilibrium, the first mover's expected profit*

$$\mathbb{E}[\pi_1^*] = \begin{cases} \frac{(a+2d+c)(a-d+c-3\beta d)}{9(1-\beta^2)}, & \text{if } d < t_1; \\ \frac{(a+2d+c)^2}{18(1+\beta)} + \frac{(a-2d+c)^2}{16(1-\beta)}, & \text{if } t_1 \leq d < t_2; \\ \frac{(a+2d+c)(a+c)}{6(1+\beta)} - \frac{(a+2d+c)^2}{18(1+\beta)^2}, & \text{if } t_2 \leq d < t_3; \\ \frac{(a+c)^2}{8}, & \text{if } d \geq t_3, \end{cases} \tag{18}$$

the second mover's expected profit

$$\mathbb{E}[\pi_2^*] = \begin{cases} \frac{(a-d-2c)^2}{9(1-\beta^2)}, & \text{if } d < t_1; \\ \frac{(a-d-2c)^2}{18(1+\beta)} + \frac{(a+2d-3c)^2}{32(1-\beta)}, & \text{if } t_1 \leq d < t_2; \\ \frac{(a-d-2c)^2}{18(1+\beta)} + \frac{1-\beta}{2}\left(\frac{a-c}{2(1-\beta)} - \frac{a+2d+c}{6(1+\beta)}\right)^2, & \text{if } t_2 \leq d < t_3; \\ \frac{(a-3c)^2+2\beta^2(a-3c)(a+c)+\beta^2(a+c)^2}{16(1-\beta^2)}, & \text{if } d \geq t_3, \end{cases} \tag{19}$$

expected consumer surplus

$$\mathbb{E}[CS_{AS}^*] = \begin{cases} \frac{(2a+d-c)^2}{36(1+\beta)} + \frac{(2a+d-c)^2}{36(1-\beta)}, & \text{if } d < t_1; \\ \frac{(2a+d-c)^2}{36(1+\beta)} + \frac{(3a-2d-c)^2}{64(1-\beta)}, & \text{if } t_1 \leq d < t_2; \\ \frac{(2a+d-c)^2}{36(1+\beta)} + \frac{1-\beta}{4}\left(\frac{a-c}{2(1-\beta)} + \frac{a+2d+c}{6(1+\beta)}\right)^2, & \text{if } t_2 \leq d < t_3; \\ \frac{(3a-c+\beta(a+c))^2}{64(1+\beta)} + \frac{(3a-c-\beta(a+c))^2}{64(1-\beta)}, & \text{if } d \geq t_3, \end{cases}$$

and the expected disposal

$$\mathbb{E}[\bar{q}_1^* - q_1^*] = \begin{cases} \frac{\beta(a+2d+c)}{3(1-\beta^2)}, & \text{if } d < t_1; \\ \frac{(1+5\beta)(a+c)-2(5+\beta)d}{12(1-\beta^2)}, & \text{if } t_1 \leq d < t_2; \\ 0, & \text{if } d \geq t_2, \end{cases}$$

all change non-monotonically with the disposal cost d.

Compared to the case where firms cannot observe each others inventory, both firms' expected profits simultaneously go up with $d \in [\max\{t_1, (a+c)(1+17\beta)/2(17+\beta)\}, t_2]$, while the expected consumer surplus decreases.

Finally, we can determine the equilibrium technology choice. Both firms producing in advance forms an equilibrium if $\mathbb{E}[\pi_A^*] \geq \mathbb{E}[\pi_2^*]$, given by (7) and (19). Rearranging yields

$$\beta \leq \beta_A(d) := \begin{cases} \frac{(a+d)^2+(a-d)^2-2(a-d-2c)}{(a+d)^2-(a-d)^2}, & \text{if } 0 < d < t_1; \\ \frac{16(a+d)^2+16(a-d)^2-16(a-d-2c)^2-9(a+2d-3c)^2}{16(a+d)^2-16(a-d)^2-16(a-d-2c)^2+9(a+2d-3c)^2}, & \text{if } t_1 \leq d < t_2; \\ \frac{(a-d)^2-\Phi\Xi+\sqrt{((a-d)^2-\Phi\Xi)^2-2(\Phi^2-a^2-d^2)(\Xi^2-\Phi^2+4ad)}}{\Xi^2-\Phi^2+4ad}, & \text{if } t_2 \leq d < \beta a; \\ \text{B}, & \text{if } \beta a \leq d < t_3; \\ \sqrt{\frac{16a^2-9(a-3c)^2}{16a^2+9(a+c)^2+18(a-3c)(a+c)}}, & \text{if } d \geq t_3, \end{cases}$$

with $\Phi = a - d - 2c$, $\Xi = 2a + d - c$, and B implicitly given by $2a^2B^3 + (2a^2 + \Xi^2 - \Phi^2)B^2 + (2\Phi\Xi - 2a^2)B - 2a^2 = 0$. At $B = 0$ the left-hand side is $-2a^2 < 0$, while at $B = 1$ it is $4a^2 + 5ac + 7ad - 5c^2 - 5cd + d^2 > 0$. Moreover, the left-hand side is strictly convex for all $B \in [0, 1)$. Hence, a unique B exists that solves the equation.

Similarly, both firms produce on the spot if $\mathbb{E}[\pi_S^*] \geq \mathbb{E}[\pi_1^*] \Leftrightarrow$

$$\beta \geq \beta_S(d) := \begin{cases} \frac{a-d+c}{3d} - \frac{(a-c)^2}{3d(a+2d+c)}, & \text{if } 0 < d < t_1; \\ \frac{16(a-c)^2-8(a+2d+c)^2-9(a-2d+c)^2}{9(a-2d+c)^2-8(a+2d+c)^2}, & \text{if } t_1 \leq d < t_2; \\ \frac{\kappa+\sqrt{\kappa^2-24\epsilon\phi}}{6\epsilon}, & \text{if } t_2 \leq d < t_3; \\ \frac{\sqrt{9(a+c)^2-8(a-c)^2}}{3(a+c)}, & \text{if } d \geq t_3, \end{cases}$$

with $\kappa = (a+2d+c)^2 - 2(a-c)^2$, $\epsilon = (a+c)(a+2d+c)$, and $\phi = (a-c)^2 - (a+2d+c)(a-d+c)$.

Finally, if $\mathbb{E}[\pi_A^*] \leq \mathbb{E}[\pi_2^*]$ and $\mathbb{E}[\pi_S^*] \leq \mathbb{E}[\pi_1^*]$, there exist two asymmetric equilibria: One firm produces with technology A and the other with technology S. Note that for $d < t_1$, $\mathbb{E}[\pi_A^*] \geq \mathbb{E}[\pi_2^*]$, i.e., the threshold for β is above one. The asymmetric equilibrium does thus not exist for $d < t_1$. In equilibrium, the expected disposal weakly decreases.

Figure 5 illustrates the equilibria. Again, an asymmetric equilibrium only exists if the disposal is costly, demand is uncertain, and there exists a cost advantage from early production. Moreover, firms only forgo the early cost advantage if both demand uncertainty and the disposal cost are simultaneously high.

A low disposal cost substitutes information about demand. With observable inventories, an additional opposing effect is present: the first mover can credibly sell a large share of her inventory. The two effects cause the non-monotonicity of the threshold functions. The first mover only discards if $d < t_2$; for large d, only the second effect remains present. $\beta_A(d)$ reaches its minimum value at $d = t_2$. Hence, there exist asymmetric equilibria in which the firms' expected profits simultaneously increase.

By contrast to the main text, with observable inventories, firms use technology A even for $c = 0$. Due to the inventory's observability there exists a strategic effect.

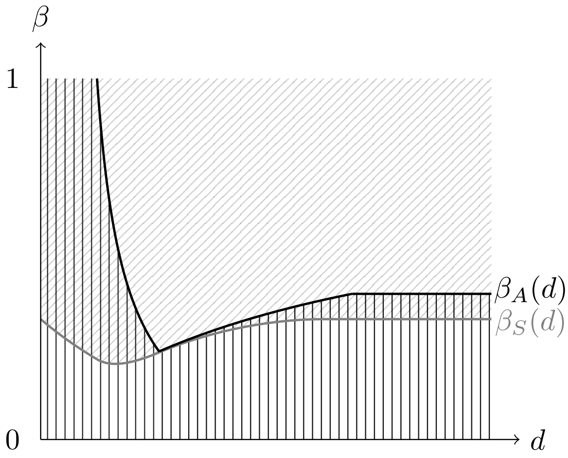
Combined Technology. Instead of only having access to one of the technologies, here we assume that firms can produce in both periods, similar as in Section 4.

After the demand has materialized, firms take their inventories as given and offer their sales volume to maximize their profit

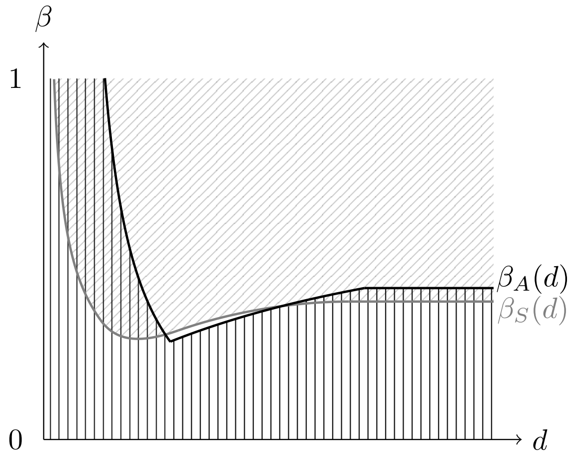
$$\pi(q_i|\bar{q}_i) = P_\vartheta(q_i + q_j)q_i - c\max\{(q_i - \bar{q}_i, 0\} - d\max\{(\bar{q}_i - q_i, 0\},$$

yielding the best response function (14) in the main text.

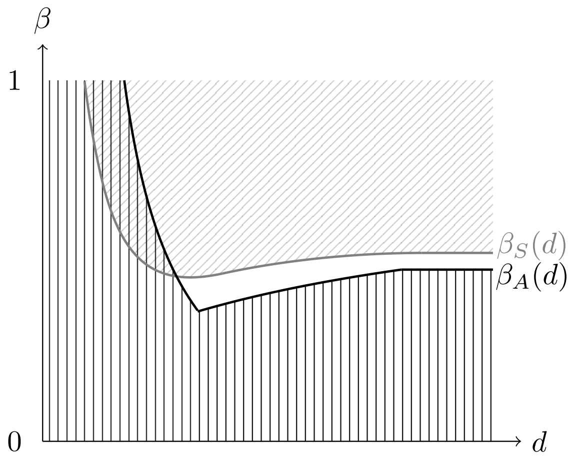
Since competitors observe inventories, we derive the sales game's subgame equilibrium following any firm's inventory choice. We denote the firm with the larger inventory by 1 and the other by 2, i.e., we assume without loss of generality $\bar{q}_1 \geq \bar{q}_2$. We can derive the unique subgame equilibrium for different ranges of parameters by combining the best response functions, which we summarize in the following Lemma.



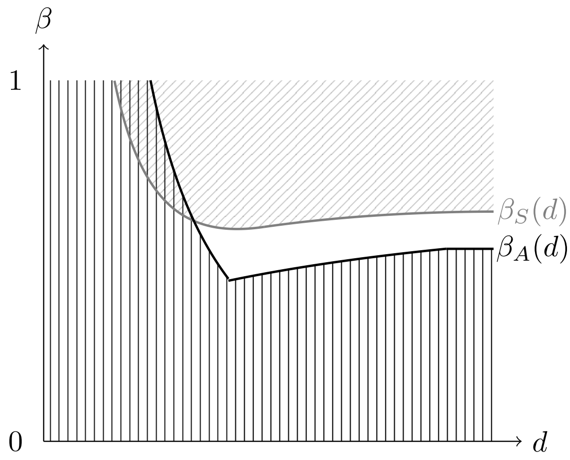
(a) No cost advantage ($c = 0$)



(b) Low cost advantage ($c = 0.1$)



(c) Medium cost advantage ($c = 0.5$)



(d) High cost advantage ($c = 1$)

Figure 5: In the diagonally gray (vetically black) shaded area, both firms produce with technology S (A). In the white area, firms choose an asymmetric strategy, one uses technology A and the other S. (Demand intercept $a = 10$ and the abscissa is truncated at 8.)

Lemma 7. *Let $\bar{q}_1 \geq \bar{q}_2$. The unique subgame equilibrium sales volumes following the inventories*

(i) $\bar{q}_1 \leq \dfrac{a-c}{3b_\vartheta}$, *are* $q_1 = q_2 = \dfrac{a-c}{3b_\vartheta}$;

(ii) $\bar{q}_1 \in [\dfrac{a-c}{3b_\vartheta}, \dfrac{a+c+2d}{3b_\vartheta}]$ *and* $\bar{q}_2 \leq \dfrac{a-c}{2b_\vartheta} - \dfrac{1}{2}\bar{q}_1$, *are* $q_1 = \bar{q}_1$ *and* $q_2 = \dfrac{a-c}{2b_\vartheta} - \dfrac{1}{2}\bar{q}_1$;

(iii) $\bar{q}_1 \leq \dfrac{a+d}{2b_\vartheta} - \dfrac{1}{2}\bar{q}_2$ *and* $\bar{q}_2 \geq \dfrac{a-c}{2b_\vartheta} - \dfrac{1}{2}\bar{q}_1$, *are* $q_1 = \bar{q}_1$ *and* $q_2 = \bar{q}_2$;

(iv) $\bar{q}_1 \geq \dfrac{a+c+2d}{3b_\vartheta}$ *and* $\bar{q}_2 \leq \dfrac{a-2c-d}{3b_\vartheta}$, *are* $q_1 = \dfrac{a+c+2d}{3b_\vartheta}$ *and* $q_2 = \dfrac{a-2c-d}{3b_\vartheta}$;

(v) $\bar{q}_1 \geq \dfrac{a+d}{2b_\vartheta} - \dfrac{1}{2}\bar{q}_2$ *and* $\bar{q}_2 \in [\dfrac{a-2c-d}{3b_\vartheta}, \dfrac{a+d}{3b_\vartheta}]$, *are* $q_1 = \dfrac{a+d}{2b_\vartheta} - \dfrac{1}{2}\bar{q}_2$ *and* $q_2 = \bar{q}_2$;

(vi) $\bar{q}_2 \geq \dfrac{a+d}{3b_\vartheta}$, *are* $q_1 = q_2 = \dfrac{a+d}{3b_\vartheta}$.

Only in subgames *(ii)* and *(iii)* does firm i sell its inventory entirely. Otherwise, it always produces additional quantities or disposes of parts.

To derive all equilibria in pure strategies, we first exclude inventory ranges that are never optimal and, therefore, contain no candidates for an equilibrium. Starting with $\bar{q}_1 < (a-c)/3(1+\beta)$, both firms produce additional quantities even if demand is below expectations. By increasing their inventory, firms decrease their costs. Similarly, if $\bar{q}_2 > (a+d)/3(1-\beta)$, both firms dispose of some quantities even if demand is above expectations. Firms decrease their costs by decreasing their inventories.

The maximal quantity that firm 1 could sell is $(a+c+2d)/3(1-\beta)$; thus, any larger inventory is never optimal. Similarly, the minimal quantity that firm 2 could sell is $(a-2c-d)/3(1+\beta)$; any lower inventory is never optimal.

If $\bar{q}_1 > (a+d)/2(1-\beta) - \bar{q}_2/2$, firm 1 discards even if demand is above its expectation. By decreasing its inventory, the firm mitigates its costs. Similarly, if $\bar{q}_2 < (a-c)/2(1+\beta) - \bar{q}_1/2$, firm 2 lowers its costs if it increases its inventory, because it produces additional quantities even if demand is below its expectation.

There remain six different areas for the equilibrium inventory strategy. We summarize them in the following Lemma.

Lemma 8. *Let $\bar{q}_1 \geq \bar{q}_2$. The following six areas may contain an equilibrium.*

(i) If $\bar{q}_1 \leq \frac{a-c}{3(1-\beta)}$ and $\bar{q}_2 \geq \frac{a-c}{2(1+\beta)} - \frac{1}{2}\bar{q}_1$, firms sell their inventories in the low-demand state and produce additional quantities if demand is above expectations.

(ii) If $\bar{q}_1 \leq \frac{a+d}{2(1+\beta)} - \frac{1}{2}\bar{q}_2$ and $\bar{q}_2 \geq \frac{a-c}{2(1-\beta)} - \frac{1}{2}\bar{q}_1$, firms sell their inventories regardless of the demand's realization.

(iii) If $\bar{q}_1 \leq \frac{a+d}{2(1-\beta)} - \frac{1}{2}\bar{q}_2$ and $\bar{q}_2 \geq \frac{a+d}{3(1+\beta)}$, firms sell their inventories if demand is above expectations and disposes of parts of it otherwise.

(iv) *If* $\bar{q}_1 \in [\frac{a-c}{3(1-\beta)}, \frac{a+d}{2(1+\beta)} - \frac{1}{2}\bar{q}_2]$ *and* $\bar{q}_2 \in [\frac{a-c}{2(1+\beta)} - \frac{1}{2}\bar{q}_1, \frac{a-c}{2(1-\beta)} - \frac{1}{2}\bar{q}_1]$*, firm* 1 *sells its inventory regardless of the demand's state, while firm* 2 *sells its inventory if demand is below expectation and produces additional quantities otherwise.*

(v) *If* $\bar{q}_1 \in [\frac{a+d}{2(1+\beta)} - \frac{1}{2}\bar{q}_2, \frac{a+d}{2(1-\beta)} - \frac{1}{2}\bar{q}_2]$ *and* $\bar{q}_2 \in [\frac{a-c}{2(1-\beta)} - \frac{1}{2}\bar{q}_1, \frac{a+d}{3(1+\beta)}]$*, firm* 1 *sells its inventory if demand is above expectation and disposes of parts of it otherwise, while firm* 2 *sells its inventory regardless of the state of demand.*

(vi) *If* $\bar{q}_1 \in [\frac{a+d}{2(1+\beta)} - \frac{1}{2}\bar{q}_2, \frac{a+c+2d}{3(1-\beta)}]$ *and* $\bar{q}_2 \in [\frac{a-2c-d}{3(1+\beta)}, \frac{a-c}{2(1-\beta)} - \frac{1}{2}\bar{q}_1]$*, firm* 1 *sells its inventory if demand is above expectation and disposes of parts of it otherwise, while firm* 2 *sells its inventory if demand is below expectations and produces additional quantities otherwise.*

Next, we analyze each area separately. As in the proof in the main text, we use $\hat{q}_1$ if the sales volume is not equal to the inventory and $\bar{q}_1$ if it does equal the inventory. In (i), firm 1's profit is $\mathbb{E}[\pi_1] = [(a-(1-\beta)(\hat{q}_1+q_{2,h})-c)\hat{q}_1 + (a-(1+\beta)(\bar{q}_1+q_{2,l})-c)\bar{q}_1]/2 + c\bar{q}_1$, implying a unique symmetric interior solution $\bar{q}_i = (a+c)/3(1+\beta)$ if $c < \min\{\beta a, d\}$. In (ii), $\mathbb{E}[\pi_1] = [(a-(1-\beta)(\bar{q}_1+q_{2,h}))\bar{q}_1 + (a-(1+\beta)(\bar{q}_1+q_{2,l}))\bar{q}_1]/2$, implying the unique symmetric equilibrium $\bar{q}_i = a/3$ if $\beta a \le \min\{c, d\}$. In (iii), $\mathbb{E}[\pi_1] = [(a-(1-\beta)(\bar{q}_1+q_{2,h})+d)\bar{q}_1 + (a-(1+\beta)(\hat{q}_1+q_{2,l})+d)\hat{q}_1]/2 - d\bar{q}_1$, implying the unique symmetric equilibrium $\bar{q}_i = (a-d)/3(1-\beta)$ if $d \le \min\{\beta a, c\}$. For the technical details, see the proof of Proposition 5 in Appendix B; the symmetric equilibrium is outcome equivalent. Hence, the same symmetric equilibrium exists regardless of whether the inventory is observed or not.

Finally, we analyze asymmetric equilibria. We first focus on (iv). The firms' best replies are technically already derived in the proof of Proposition 5. The unique equilibrium candidate is $\bar{q}_1 = q_{1,h} = q_{1,l} = 2a/(5+\beta)$ and $\bar{q}_2 = q_{2,l} = (3a+5c-\beta a+\beta c)/2(1+\beta)(5+\beta)$, which is only an equilibrium if $\beta a \ge c$, $a+5c \ge \beta(7a-c)$ and $a+5c \le 10d+\beta(2d-5a-c)$. However, $\beta(7a-c) \le 10d+\beta(2d-5a-c) \Leftrightarrow 6a \le d+5\beta d$, resulting in a contradiction.

Next, we show that in (v), no equilibrium exists. The unique candidate is given by $\bar{q}_1 = q_{1,h} = (3a+\beta a-d(5-\beta))/2(1-\beta)(5-\beta)$, and $\bar{q}_2 = q_{2,h} = q_{2,l} = 2a/(5-\beta)$. Necessary conditions for its existence are $d \le \beta a$ and $d \ge (a+7\beta a)/(5-\beta)$. Hence, the range for d only exists if $a+2\beta a+\beta^2 a \le 0$, which yields a contradiction.

Lastly, we derive the equilibrium in (vi). The inventories' first order conditions are already derived in the proof of Proposition 5. This implies the unique equilibrium candidate $\bar{q}_1 = q_{1,h} = (a+c-2d)/2(1-\beta)$, $q_{1,l} = (a-2c+3d)/4(1+\beta)$, $\bar{q}_2 = q_{2,l} = (a+2c-d)/2(1+\beta)$, and $q_{2,h} = (a-3c+2d)/4(1-\beta)$. This indeed forms an interior equilibrium if $d \ge (a+c)/10$, $(7+\beta)d \le a+3\beta a+4c$, and $4d \ge a-3\beta a+7c-\beta c$. We summarize this equilibrium in the following proposition.

Proposition 6. *If* $\max\{(a+c)/10, (a+7c-3\beta a-\beta c)/4\} \le d \le \min\{(a+4c+3\beta a)/(7+\beta), a-2c\}$*, the firms' inventories*

$$\bar{q}_1^* = \frac{a+c-2d}{2(1-\beta)}, \qquad \bar{q}_2^* = \frac{a+2c-d}{2(1+\beta)},$$

and their sale volumes

$$q^*_{1,h} = \bar{q}_i; \qquad q^*_{1,l} = \tfrac{a-2c+3d}{4(1+\beta)};$$
$$q^*_{2,h} = \tfrac{a-3c+2d}{4(1-\beta)}; \quad q^*_{2,l} = \bar{q}_2.$$

Firm 1 disposes of parts of her inventory if demand is lower than expected; firm 2 produces additional quantities if demand is higher than expected. Otherwise, firms sell their inventories. Firm 1's expected profit

$$\mathbb{E}[\pi^*_1] = \frac{(a-2c+3d)^2}{32(1+\beta)} + \frac{(a+c-2d)^2}{16(1-\beta)},$$

is ambiguous with the disposal cost. Firm 2's expected profit

$$\mathbb{E}[\pi^*_2] = \frac{(a-3c+2d)^2}{32(1-\beta)} + \frac{(a+2c-d)^2}{16(1+\beta)},$$

increases with d. The expected consumer surplus and expected disposal

$$\begin{aligned}\mathbb{E}[CS^*] &= \frac{(3a-c-2d)^2}{64(1-\beta)} + \frac{(3a+2c+d)^2}{64(1+\beta)};\\ \mathbb{E}[\bar{q}^*_1 - q^*_1] &= \frac{a+3\beta a+4c-(7+\beta)d}{8(1-\beta^2)},\end{aligned}$$

decrease with the disposal cost d. Moreover, the expected price $\mathbb{E}[P] = (2a-c+d)/8$ increases with the disposal cost.

In contrast to the symmetric equilibrium, expected prices increase with the disposal cost. Firms decrease their inventories, and thus the expected trade volume decreases, resulting in a higher price. Firms hand an increase in their cost over to consumers. Interestingly, expected prices decrease with c. The higher the production cost in the second period, the more firms increase their inventory, which is produced at a zero cost. A part of this reduced production cost is handed over to consumers.

Expected disposal decreases in its cost, as in the other cases. The larger firm is the one discarding if demand is below expectations. A higher disposal cost decreases the firm's inventory and disposal. Therefore, its sales volume in the high-demand state is lower, yet higher if demand is below expectations. By contrast, the smaller firm sells less if demand is below expectations and increases its sales volume if demand is above expectations.

Profits and consumer surplus are convex functions of d. Firm 1's profit is ambiguously affected by d. On the one hand, firm 1's costs increase if demand is below expectations. On the other hand, firm 1's sales volume also increases, resulting in a larger market share. The total effect on the profit is thus ambiguous.

Firm 2 mainly produces in the second period, i.e., with an information advantage: the higher the disposal cost, the more severe this information advantage, increasing firm 2's expected profit.

Consequently, there exist parameter ranges where both firms' expected profits increase simultaneously. Consumer surplus, however, decreases with d. Firms produce less inventory if the disposal is costly. If demand is higher than expected, firms indeed produce additional quantities, yet at a higher cost. Therefore, the trade volume decreases and, thereby, so does consumer surplus.

Finally, we present a numerical example to show that firms may oppose to observe their competitor's inventory. Suppose $a = 1$, $c = 1/4$, and $\beta = 3/4$. With $d = 1/2$, it follows that $\mathbb{E}[\pi_2^*] = 0.231 \geq \mathbb{E}[\pi_i^*] = 0.1746 \geq \mathbb{E}[\pi_1^*] = 0.087$, thus the smaller firm prefers if inventories are observable but the larger one is worse off. With $d = 1/3$, $\mathbb{E}[\pi_i^*] = 0.1746 \geq \mathbb{E}[\pi_2^*] = 0.1536 \geq \mathbb{E}[\pi_1^*] = 0.1252$, thus both firms prefers if inventories are private. Finally, with $d = 1/5$, $\mathbb{E}[\pi_1^*] = 0.2022 \geq \mathbb{E}[\pi_i^*] = 0.1879 \geq \mathbb{E}[\pi_2^*] = 0.1132$, thus the larger firm prefers if inventories are observed.

Perfectly Elastic Demand. In this section, we adjust the demand function for perfect elasticity if firms have the combined technology, i.e, can produce in both periods. Formally, let the inverse demand function be $P_\vartheta(Q_\vartheta) = \max\{a - b_\vartheta Q_\vartheta, 0\}$.

Monopoly. After the demand has materialized, the monopolist offers the sales volume to

$$\max_{q_\vartheta} \pi_\vartheta(q_\vartheta; \bar{q}) = q_\vartheta \max\{0, a - b_\vartheta q_\vartheta\} - c \max\{0, q_\vartheta - \bar{q}\} - d \max\{0, \bar{q} - q_\vartheta\},$$

which is a weakly concave and continuous objective function. The firm may make a negative profit if it disposes of large inventories, i.e., if $\bar{q} \geq (a+d)^2/4db_\vartheta$. However, the price is zero if $q_\vartheta \geq a/b_\vartheta$. Since $(a+d)^2/4db_\vartheta \geq a/b_\vartheta \Leftrightarrow (a-d)^2 \geq 0$, the firm can avoid losses by offering its entire inventory. Accordingly, the optimal sales volume is

$$q_\vartheta(\bar{q}) = \begin{cases} \frac{a-c}{2b_\vartheta}, & \text{if } \bar{q} < \frac{a-c}{2b_\vartheta}; \\ \bar{q}, & \text{if } \frac{a-c}{2b_\vartheta} \leq \bar{q} < \frac{a+d}{2b_\vartheta}; \\ \frac{a+d}{2b_\vartheta}, & \text{if } \frac{a+d}{2b_\vartheta} \leq \bar{q} < \frac{a+d}{2b_\vartheta}\frac{a+d}{2d}; \\ \bar{q}, & \text{if } \bar{q} \geq \frac{a+d}{2b_\vartheta}\frac{a+d}{2d}. \end{cases}$$

Obviously, $\bar{q} < (a-c)/2(1+\beta)$ is not profit-maximizing, the firm decreases its cost if it produces more in the first period. Similarly, $\bar{q} > (a+d)/2(1-\beta)$ is not optimal. Decreasing the inventory lowers the firm's disposal costs.

For $c \neq d$, the firm has to sell its entire inventory either in the high- or low-demand state. For $c = d$, this is still optimal. However, there may exist multiple optimal inventory levels, which all result in the equivalent sales volume. For simplicity, we assume $c \neq d$.

$$\mathbb{E}[\pi_\vartheta] = \begin{cases} \frac{1}{2}\left(a - (1+\beta)\bar{q}\right)\bar{q} + \frac{1}{2}\left((a - c - (1-\beta)q_h)q_h + c\bar{q}\right), & \text{if } \bar{q} \in \mathbb{Q}_1; \\ \frac{1}{2}\left(a - (1+\beta)\bar{q}\right)\bar{q} + \frac{1}{2}\left(a - (1-\beta)\bar{q}\right)\bar{q}, & \text{if } \bar{q} \in \mathbb{Q}_2; \\ \frac{1}{2}\left((a + d - (1+\beta)q_l)q_l - d\bar{q}\right) + \frac{1}{2}\left(a - (1-\beta)\bar{q}\right)\bar{q}, & \text{if } \bar{q} \in \mathbb{Q}_3; \\ \frac{1}{2}0 + \frac{1}{2}\left(a - (1-\beta)\bar{q}\right)\bar{q}, & \text{if } \bar{q} \in \mathbb{Q}_4, \end{cases}$$

with $\mathbb{Q}_1 = \left[\frac{a-c}{2(1+\beta)}, \min\left\{\frac{a-c}{2(1-\beta)}, \frac{a+d}{2(1+\beta)}\right\}\right)$, $\mathbb{Q}_2 = \left(\frac{a-c}{2(1-\beta)}, \frac{a+d}{2(1+\beta)}\right]$, $\mathbb{Q}_3 = \left(\max\left\{\frac{a+d}{2(1+\beta)}, \frac{a-c}{2(1-\beta)}\right\}, \min\left\{\frac{a+d}{2(1-\beta)}, \frac{a+d}{2(1+\beta)}\frac{a+d}{2d}\right\}\right]$, and $\mathbb{Q}_4 = \left(\max\left\{\frac{a+d}{2(1+\beta)}\frac{a+d}{2d}, \frac{a-c}{2(1-\beta)}\right\}, \frac{a+d}{2(1-\beta)}\right]$. There exists a local maximum in the first three parts,

$$\bar{q} = \begin{cases} \frac{a+c}{2(1+\beta)}, & \text{if } c < \min\{\beta a, d\}; \\ \frac{a}{2}, & \text{if } \beta a \leq \min\{c, d\}; \\ \frac{a-d}{2(1-\beta)}, & \text{if } d < \min\{\beta a, c\} \text{ and } \beta \leq \frac{a^2+3d^2}{a^2+4ad-d^2}, \end{cases}$$

whereas the last part implies a local maximum at $\bar{q} = \frac{a}{2(1-\beta)}$ if $\beta \geq \frac{a^2+d^2}{a^2+4ad+d^2}$. The first local maximum implies an expected profit of

$$\mathbb{E}[\pi_\vartheta] = \begin{cases} \frac{(a+c)^2}{8(1+\beta)} + \frac{(a-c)^2}{8(1-\beta)}, & \text{if } c < \min\{\beta a, d\}; \\ \frac{a^2}{4}, & \text{if } \beta a \leq \min\{c, d\}; \\ \frac{(a+d)^2}{8(1+\beta)} + \frac{(a-d)^2}{8(1-\beta)}, & \text{if } d < \min\{\beta a, c\} \text{ and } \beta \leq \frac{a^2+3d^2}{a^2+4ad-d^2}, \end{cases}$$

and the second $\mathbb{E}[\pi_\vartheta] = \frac{a^2}{8(1-\beta)}$ if $\beta \geq \frac{a^2+d^2}{a^2+4ad+d^2}$. The two coexist for certain parameter regions.

Comparing the two, we get the optimal inventory. If $c < \min\{\beta a, d\}$, selling at a zero price yields a higher expected profit if $\beta \geq (a^2 + 2c^2)/(a^2 + 4ac)$. Note that this is larger than $(a^2 + d^2)/(a^2 + 4ad + d^2)$ if $c < d$. For $\beta a \leq \min\{c, d\}$, selling at a zero price is only better if $\beta \geq 1/2$. This, however, contradicts $\beta \leq c/a \leq 1/2$. Finally, in the last part, selling at a zero price is more profitable if $\beta \geq (a^2 + 2d^2)/(a^2 + 4ad)$. Note that this is higher than $(a^2 + d^2)/(a^2 + 4ad + d^2)$. To summarize

$$\mathbb{E}[\pi^*_\vartheta] = \begin{cases} \frac{(a+c)^2}{8(1+\beta)} + \frac{(a-c)^2}{8(1-\beta)}, & \text{if } c < d \text{ and } \beta \in \left[\frac{c}{a}, \frac{a^2+2c^2}{a^2+4ac}\right]; \\ \frac{a^2}{4}, & \text{if } \beta \leq \min\left\{\frac{c}{a}, \frac{d}{a}\right\}; \\ \frac{(a+d)^2}{8(1+\beta)} + \frac{(a-d)^2}{8(1-\beta)}, & \text{if } d < c \text{ and } \beta \in \left[\frac{d}{a}, \frac{a^2+2d^2}{a^2+4ad}\right]; \\ \frac{a^2}{8(1-\beta)}, & \text{else.} \end{cases}$$

As in the case with distinct technologies in Appendix A, the firm may not produce in the second stage if β is large. Figure 3 illustrates the parameters for which the firm produces after the demand's realization.

Competition. Similar as before, a firm may make a loss if it discards. The optimal sales volume if a firm disposes of parts of its inventory is $q_{i,\vartheta} = (a + d)/2b_\vartheta - q_{j,\vartheta}/2$, resulting in a negative profit if $\bar{q}_i \geq b_\vartheta((a+d)/2b_\vartheta - q_{j,\vartheta}/2)^2/d$. Note that the price is zero if the firm offers $q_{i,\vartheta} \geq a/b_\vartheta - q_{j,\vartheta}$. Since $b_\vartheta((a + d)/2b_\vartheta - q_{j,\vartheta}/2)^2/d \geq a/b_\vartheta - q_{j,\vartheta} \Leftrightarrow (a - d - b_\vartheta q_{j,\vartheta})^2 \geq 0$, the firm can avoid a loss by selling its entire inventory.

A firm's optimal response function in the second stage can be written as

$$q_{i,\vartheta}(q_{j,\vartheta};\bar{q}_i) = \begin{cases} \frac{a-c}{2b_\vartheta} - \frac{1}{2}q_{j,\vartheta}, & \text{if } \bar{q}_i < \frac{a-c}{2b_\vartheta} - \frac{1}{2}q_{j,\vartheta}; \\ \bar{q}_i, & \text{if } \frac{a-c}{2b_\vartheta} - \frac{1}{2}q_{j,\vartheta} \leq \bar{q}_i < \frac{a+d}{2b_\vartheta} - \frac{1}{2}q_{j,\vartheta}; \\ \frac{a+d}{2b_\vartheta} - \frac{1}{2}q_{j,\vartheta}, & \text{if } \frac{a+d}{2b_\vartheta} - \frac{1}{2}q_{j,\vartheta} \leq \bar{q}_i < \frac{b_\vartheta}{d}\left(\max\{0, \frac{a+d}{2b_\vartheta} - \frac{1}{2}q_{j,\vartheta}\}\right)^2; \\ \bar{q}_i, & \text{if } \bar{q}_i \geq \frac{b_\vartheta}{d}\left(\max\{0, \frac{a+d}{2b_\vartheta} - \frac{1}{2}q_{j,\vartheta}\}\right)^2, \end{cases}$$

whenever it is larger than zero and $q_{j,\vartheta} \leq (a-d)/b_\vartheta$. A firm should sell its entire inventory at a positive price in at least one state. This directly results in the candidates for an equilibrium, summarized in Table 11.

(i)	$\bar{q}_i = \frac{2a-(1+\beta)q_{j,l}-(1-\beta)q_{j,h}}{4}$	$q_{i,l} = \bar{q}_i$	$q_{i,h} = \bar{q}_i$
(ii)	$\bar{q}_i = \frac{a-d-(1-\beta)q_{j,h}}{2(1-\beta)}$	$q_{i,l} = \frac{a+d}{2(1+\beta)} - \frac{q_{j,l}}{2}$	$q_{i,h} = \bar{q}_i$
(iii)	$\bar{q}_i = \frac{a-d-(1+\beta)q_{j,l}}{2(1+\beta)}$	$q_{i,l} = \bar{q}_i$	$q_{i,h} = \frac{a+d}{2(1-\beta)} - \frac{q_{j,h}}{2}$
(iv)	$\bar{q}_i = \frac{a+c-(1+\beta)q_{j,l}}{2(1+\beta)}$	$q_{i,l} = \bar{q}_i$	$q_{i,h} = \frac{a-c}{2(1-\beta)} - \frac{q_{j,h}}{2}$
(v)	$\bar{q}_i = \frac{a+c-(1-\beta)q_{j,h}}{2(1-\beta)}$	$q_{i,l} = \frac{a-c}{2(1+\beta)} - \frac{q_{j,l}}{2}$	$q_{i,h} = \bar{q}_i$
(vi)	$\bar{q}_i = \frac{a-(1-\beta)q_{j,h}}{2(1-\beta)}$	$q_{i,l} = \bar{q}_i$	$q_{i,h} = \bar{q}_i$
(vii)	$\bar{q}_i = \frac{a-(1+\beta)q_{j,l}}{2(1+\beta)}$	$q_{i,l} = \bar{q}_i$	$q_{i,h} = \bar{q}_i$

Table 11: Equilibrium candidates

The first five cases are equivalent to Section 4. It follows directly that the same equilibrium exists whenever discarding does not result in a negative profit. Formally,

$$\bar{q}_i^* = \begin{cases} \frac{a+c}{3(1+\beta)}, & \text{if } c < \min\{\beta a, d\}; \\ \frac{a}{3}, & \text{if } \beta a \leq \min\{c, d\}; \\ \frac{a-d}{3(1-\beta)}, & \text{if } d < \min\{\beta a, c\} \text{ and } \beta \leq \frac{a^2-ad+4d^2}{a^2+5ad-2d^2}. \end{cases} \tag{20}$$

Whenever firm i plays (vi), firm j has to play (vi), too: The price in the low-demand state is going to be zero, any other case is not a best reply. Symmetry thus directly implies the equilibrium $\bar{q}_i = a/3(1-\beta)$. This indeed forms an equilibrium if $\beta \geq \frac{(2a+3d)(4a+3d)-12a\sqrt{ad+2d^2}}{(4a+3d)^2+12ad}$.

Similarly, if firm i plays (vii), firm j has to play (vii), too. Thus, $\bar{q}_i = a/3(1+\beta)$. The price in the high-demand state has to be zero, formally, $a-(1-\beta)2\bar{q}_i \leq 0 \Leftrightarrow 1+5\beta \leq 0$, resulting in a contradiction.

Thus, there may exist multiple symmetric equilibria. We focus on the profit-maximizing equilibrium. Comparing the expected profit

$$\mathbb{E}[\pi_i] = \begin{cases} \frac{(a+c)^2}{18(1+\beta)} + \frac{(a-c)^2}{18(1-\beta)}, & \text{if } c < \min\{\beta a, d\}; \\ \frac{a^2}{9}, & \text{if } \beta a \leq \min\{c, d\}; \\ \frac{(a+d)^2}{18(1+\beta)} + \frac{(a-d)^2}{18(1-\beta)}, & \text{if } d < \min\{\beta a, c\} \text{ and } \beta \leq \frac{a^2-ad+4d^2}{a^2+5ad-2d^2}, \end{cases} \tag{21}$$

to $\mathbb{E}[\pi_i] = \frac{a^2}{18(1-\beta)}$ if $\beta \geq \frac{(2a+3d)(4a+3d)-12a\sqrt{ad+2d^2}}{(4a+3d)^2+12ad}$ yields the same threshold as for the monopolist.

Note that $(a^2 + 2d^2)/(a^2 + 4ad) \leq (a^2 - ad + 4d^2)/(a^2 + 5ad - 2d^2)$ for $d < c \leq a/2$. Thus, there exists a parameter range in which the monopolist discards, yet competitive firms do not, and sell their entire inventory at a price of zero instead. The difference arises since an individual firm faces a relatively smaller demand.

To summarize, if $\frac{a^2+2c^2}{a^2+4ac} \geq \frac{(2a+3d)(4a+3d)-12a\sqrt{ad+2d^2}}{(4a+3d)^2+12ad}$, and $\frac{a^2+2d^2}{a^2+4ad} \geq \frac{(2a+3d)(4a+3d)-12a\sqrt{ad+2d^2}}{(4a+3d)^2+12ad}$,[29] the unique profit maximizing expected profit for the competitive firms is

$$\mathbb{E}[\pi_i^*] = \begin{cases} \frac{(a+c)^2}{18(1+\beta)} + \frac{(a-c)^2}{18(1-\beta)}, & \text{if } c < d \text{ and } \beta \in [\frac{c}{a}, \frac{a^2+2c^2}{a^2+4ac}]; \\ \frac{a^2}{9}, & \text{if } \beta \leq \min\{\frac{c}{a}, \frac{d}{a}\}; \\ \frac{(a+d)^2}{18(1+\beta)} + \frac{(a-d)^2}{18(1-\beta)}, & \text{if } d < c \text{ and } \beta \in [\frac{d}{a}, \frac{a^2-ad+4d^2}{a^2+5ad-2d^2}]; \\ \frac{a^2}{9(1-\beta)}, & \text{else.} \end{cases}$$

We directly see that the monopolist and the competitive firm use technology S for the same parameter range. This is illustrated in Figure 3 in the main text.

[29] We tested the inequality for several parameter combinations; all satisfied the inequalities.