Consumer-Optimal Disclosure with Costly Information Acquisition

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Abstract

I study the question of how much product information should be available to consumers. A monopolist sells one unit of product. The consumer is initially uninformed of the product value but can incur costs to observe a noisy signal of his valuation. I show that if it is costly to acquire information, consumer surplus is increasing in the informativeness of the signal, because the seller sets a lower price to deter the consumer's learning. I also show that there is a positive level of information acquisition cost that maximizes both consumer and total surplus.

1 Introduction

I study the question of how much product information should be available to consumers, who incur costs to process information. To do so, I consider a monopoly pricing model with costly information acquisition: The seller holds one unit of product, which she does not value. The seller posts a price as a take-it-or-leave-it offer. After observing the price, the consumer decides whether to incur costs and observe a noisy signal of his valuation, and then he makes purchase decision. The main focus is on how consumer welfare depends on the informativeness of the signal and the cost to acquire it.

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Consumers often acquire product information prior to trade. For example, they may visit online shopping websites and read product descriptions or go to brick and mortar stores to see product samples. These activities are costly but enable consumers to form estimates of their willingness to pay. Now, suppose that, say, a new customer review website appears. It is still costly for consumers to visit the website and process information; however, the website provides more informative signals of their valuations compared to other traditional means. How does this new information environment affect the welfare of sellers and consumers? The question is not new; however, this paper points to a new economic benefit of the greater availability of information.

The first finding is that if it is sufficiently costly for the consumer to acquire information, we can maximize consumer and total surplus by disclosing as much information as possible, *even though the consumer does not acquire it.* The logic is as follows. If information acquisition is costly, the seller prefers to set a low price to induce the consumer to buy the product without acquiring information. If the signal becomes more informative, the consumer has a greater incentive to observe it. This, in turn, implies that the seller has to set an even lower price to deter learning. The result illustrates a new channel through which the greater availability of product information benefits consumers.

A natural question is, in the first place, whether the cost of information acquisition hurts consumers. The first result does not answer this question because I fix the cost and vary only the informativeness of the signal. Indeed, one might think that higher costs hurt consumers because uninformed consumers may sometimes buy products whose values fall under prices. However, I show that both consumer and total surplus are typically maximized when the consumer incurs positive costs to acquire information. Intuitively, when the consumer can acquire information cheaply but not freely, the seller prefers to lower the price to deter learning. I show that the benefit from low prices exceeds the cost of potentially buying the product with low values.

This work relates to two strands of existing literature: information disclosure and mechanism design with information acquisition. For example, Lewis and Sappington (1994), Johnson and Myatt (2006) and Ivanov (2013) study sellers' incentives to disclose information to buyers. This paper differs from their works in three aspects: First, the consumer in my model has to incur costs to observe information. Second, I focus on an information structure maximizing consumer surplus, which would be relevant when we consider regulators or online platforms. Third, I consider all

Blackwell experiments of the consumer's valuation instead of a particular class of signals. This paper also relates to Wang (2017), which shows that a firm has an incentive to disclose partial information to deter consumers from searching for additional information. In Wang (2017), consumers freely acquire information provided by the firm, and they can subsequently incur costs to be perfectly informed about their values. In my model there is no free information, and the main variable of interest is information that consumers can obtain at costs.

Second, the paper relates to works on mechanism design with information acquisition in economics and marketing literature (Crémer and Khalil, 1992; Crémer et al., 1998a,b; Szalay, 2009; Guo and Zhang, 2012; Shi, 2012; Terstiege, 2016; Ye and Zhang, 2017; Lagerlöf and Schottmüller, 2018a,b). The literature considers richer settings such as auctions and nonlinear pricing. However, it usually focuses on the characterization of optimal mechanisms and does not consider comparative statics. Two exceptions are Lagerlöf and Schottmüller (2018a,b), which conduct local comparative statics in search costs in a monopoly insurance model. They also show that a positive search cost can maximize consumer surplus in a numerical example. I study a more parsimonious setting but offers richer comparative statics in value distributions and information acquisition costs. Finally, Roesler and Szentes (2017) studies a model in which the consumer commits to an information acquisition policy to influence the seller's pricing. Later I show how their result can change if learning is costly.

2 Model

The model consists of a seller, a consumer, and an information designer. The seller holds one unit of product, and her valuation is zero. The consumer's valuation is $v \in \mathbb{R}$ drawn from the cumulative distribution function F, which is commonly known to all players. For notational simplicity, I define $F(x)$ as the probability of $v < x$. F satisfies $F(0) = 0$ and has a mean of $\mu := \int_{-\infty}^{+\infty} v dF(v) > 0$. Thus, it is always efficient to trade.

A *signal* (S, σ) is a pair of a signal realization space S and a function $\sigma : v \mapsto \sigma(v) \in \Delta(S)$, where $\Delta(S)$ is the set of all probability distributions over S. Hereafter, I often write a signal as σ instead of (S, σ). I define the *fully informative signal* as a signal σ^* that reveals v, e.g., $\sigma^*(v)$ draws a realization $s = v$ for any possible v.

The timing of the game is as follows. First, the designer publicly chooses a signal σ from the set of all signals. Second, the seller sets price p, which the consumer observes. Then, Nature draws the value $v \sim F$ and a signal realization $s \sim \sigma(v)$. At this point, neither the seller nor the consumer observes (v, s). The consumer then chooses whether to learn s. If the consumer chooses to learn, he incurs a cost of $c \geq 0$ and observes s.[1] Otherwise, he does not incur any costs and does not observe s. Finally, the consumer decides whether to buy the product.

The payoff of each player is as follows. Let $\gamma = 0$ if the consumer does not observe a signal realization, and $\gamma = c$ if he does. If the consumer purchases the product, his ex post payoff is $v - p - \gamma$; otherwise, his ex post payoff is $-\gamma$. The seller's payoff is her revenue. Both the consumer and the seller are risk neutral. I do not specify the preferences of the designer for now, because I study how the equilibrium depends on the designer's strategy.

The solution concept is subgame perfect equilibrium in which the seller breaks ties in favor of the consumer when she sets a price.[2] Note that if the consumer does not acquire information, he buys the product if and only if $\mu \geq p$. If the consumer observes s, he compares p with the expected valuation conditional on s. Whenever it is clear from context, I use "equilibrium" to mean subgame prefect equilibrium of the subgame in which the designer has chosen some signal.

There are several ways to interpret the designer. We may view the designer as a regulator or an online platform which chooses a regulation or a platform design to control what product information is available to consumers. We can also think of different strategies of the designer as different information environments. For instance, a more informative signal might correspond to a situation in which the consumer can access a new customer review website.

3 Equilibrium Analysis with a Fixed Signal

In this section, I fix a signal σ of the designer and solves the corresponding subgame between the seller and the consumer. I solve the game in three steps. First, I derive the seller's optimal price that deters information acquisition. Second, I derive the highest price such that the consumer prefers to acquire information rather than exiting the market. Using these prices, I characterize an

[1] Hereafter, I use "information acquisition," "learning s," and "inspection" interchangeably.

[2] As is common in this type of game, we do not need perfect Bayesian equilibrium because the designer chooses a signal before observing a realized valuation.

equilibrium.[3]

Any signal σ induces a distribution over posterior beliefs about v. Moreover, because the consumer is risk neutral, it is enough to keep track of the distribution of posterior means. Thus, given a signal σ, let G denote the distribution of posterior expectations induced by σ and F.

Given price $p \leq \mu$, the consumer prefers not to learn s if and only if

$$\begin{aligned} & \mu - p \geq \int_0^{+\infty} \max(x-p, 0)dG(x) - c \qquad (1) \\ \iff & 0 \geq \int_0^{+\infty} \max(0, p-x)dG(x) - c \\ \iff & c \geq \int_0^p p - xdG(x) \\ \iff & c \geq \int_0^p G(x)dx. \end{aligned}$$

I obtain the second inequality by subtracting $\mu - p = \int_0^{+\infty} xdG(x) - p$ from both sides of the first inequality. The last inequality follows from the integration by parts.

For each $c > 0$, define $x_0(c)$ implicitly by $c = \int_0^{x_0(c)} G(x)dx$. For $c = 0$, this equation does not uniquely determine $x_0(c)$, so I define $x_0(0)$ as the infimum of the support of G. I sometimes write $x_0(c)$ as x_0 for simplicity or as $x_0(c, G)$ to emphasize that $x_0(c)$ also depends on G. Note that if c is sufficiently high so that $x_0(c) \geq \mu$ holds, the seller can extract full surplus by charging price μ. Thus, we obtain the following.

Lemma 1. *Among the prices under which the consumer buys the product without observing a signal, price $p_0(c) := \max(x_0(c), \mu)$ uniquely maximizes revenue, where $x_0(c)$ satisfies $c = \int_0^{x_0(c)} G(x)dx$ for any $c \geq 0$.*

Second, I derive the highest price that makes it individually rational for the consumer to acquire information. Note that if the consumer is willing to learn s given price $p^M(G) := \min\left(\arg\max_p p[1 - G(p)]\right)$, the seller prefers to set $p^M(G)$. In contrast, if cost c is so high that the consumer obtains a negative payoff by acquiring information, the seller has to set a lower price than $p^M(G)$.

[3]The analysis generalizes a part of the analysis by Wang (2017). This generalization is important for my analysis because depending on signal σ, the distribution G of posterior means can be discontinuous and the reliability function $1 - G$ may not be log-concave.

Note that given price p, the consumer prefers to learn s rather than no purchase if and only if

$$\begin{aligned} &\int_0^{+\infty} \max(x-p,0)dG(x) - c \geq 0 \\ \iff &\int_p^{+\infty} (x-p)dG(x) \geq c \\ \iff &\int_p^{+\infty} 1 - G(x)dx \geq c. \end{aligned} \tag{2}$$

For $c > 0$, define $x_1(c)$ implicitly by $c = \int_{x_1(c)}^{+\infty} 1 - G(x)dx$. Also, let $x_1(0)$ be the supremum of the support of G. Given price p, the consumer prefers to observe a signal rather than existing the market if and only if $p \leq x_1(c)$. Note that depending on c, the consumer may buy the product without inspection at price $x_1(c)$.

Lemma 2. *Define $p_1(c) := \arg\max_{p \leq x_1(c)} p[1 - G(p)]$. Then, $p_1(c)$ is the optimal price subject to the constraint that the consumer observes a signal instead of exiting the market.*[4]

I define a cutoff c^* as follows. $p_0(c)$ in Lemma 1 is continuous, and it is strictly increasing in c until it hits μ. Also, $p_1(c)[1 - G(p_1(c))]$ is continuous and decreasing in c.[5] Moreover, it holds that $p_0(0) = x_0(0) \leq p_1(0)[1 - G(p_1(0))] = p^M(G)[1 - F(p^M(G))] \leq \mu = \lim_{c \to +\infty} p_0(c)$. Let c^* denote the unique level of the cost satisfying

$$p_0(c^*) = p_1(c^*)[1 - G(p_1(c^*))]. \tag{3}$$

If information acquisition cost is c^*, the seller is indifferent between deterring the consumer's learning by charging $p_0(c^*)$ and inducing it by charging $p_1(c^*)$.

Proposition 1. *In equilibrium, the consumer acquires information if and only if $c < c^*$. If $c < c^*$, the seller sets a price of $p_1(c)$. If $c \geq c^*$, the seller sets a price of $p_0(c) \leq p_1(c)$.*

[4] If $1 - G$ is log-concave, $p_1(c)$ simplifies to $\min(p^M(G), x_1(c))$. However, $1 - G$ fails to be log-concave for a wide range of signals.

[5] The continuity holds for the following reason: If $p_1(c)[1 - G(p_1(c))]$ is discontinuous at some c', then there is $\delta > 0$ such that for any $\varepsilon > 0$, $\max_{p \leq x_1(c')} p[1 - G(p)] - \max_{p \leq x_1(c'+\varepsilon)} p[1 - G(p)] > \delta$. $p_1(c') = x_1(c')$ holds, because if $p_1(c') < x_1(c')$, $p_1(c') \leq x_1(c' + \varepsilon)$ holds for a sufficiently small $\varepsilon > 0$. However, if the seller sets price $x_1(c' + \varepsilon)$ given cost $c' + \varepsilon$, then her revenue $p(x_1(c' + \varepsilon))[1 - G(x_1(c' + \varepsilon))]$ converges to $p(x_1(c')[1 - G(x_1(c'))]$ as $\varepsilon \to 0$ because $p[1 - G(p)]$ is left-continuous and $x_1(c' + \varepsilon)$ converges to $x_1(c')$ from below as $\varepsilon \to 0$.

Proof. First, $c \geq c^*$ implies $p_0(c) \geq p_1(c)[1 - G(p_1(c))]$. This implies that the seller prefers to set $p_0(c)$ to deter learning, because if the seller chooses another price and the consumer learns s, the seller's revenue is at most $p_1(c)[1 - G(p_1(c))]$. (The seller's tie-breaking rule implies that she sets $p_0(c^*) \leq p_1(c^*)$ at $c = c^*$.) Second, if $c < c^*$, $p_0(c) < p_1(c)[1 - G(p_1(c))]$. This implies $p_0(c) < p_1(c)$, which implies that the consumer prefers to learn s given price $p_1(c)$. Thus, $p_1(c)$ maximizes revenue among all prices that induce learning. Therefore, if $c < c^*$, the seller posts price $p_1(c)$ and the consumer observes a signal realization. □

Before proceeding to the comparative statics, I summarize the equilibrium payoffs.

Corollary 1. *In equilibrium, the following holds.*

- *If $c < c^*$, the seller and the consumer obtain expected payoffs of $p_1(c)[1 - G(p_1(c))]$ and $\int_{p_1(c)}^{+\infty} 1 - G(x)dx - c$, respectively.*
- *If $c \geq c^*$, the seller and the consumer obtain expected payoffs of $p_0(c)$ and $\mu - p_0(c)$, respectively.*

4 Optimality of Full Disclosure

This section considers the following question: To maximize consumer surplus, how much and what kind of information should the designer disclose? This is a difficult problem because we have to consider all signals (i.e., all Blackwell experiments of $v \sim F$) and study how they affect the distributions of posterior means and prices. Indeed, the case of $c = 0$ was only recently solved by Roesler and Szentes (2017), which shows that partially informative signals often maximize consumer surplus.

The following result shows that, however, full disclosure is optimal if it is significantly costly to acquire information. To state the result, let c^* be the cutoff in Proposition 1. Namely, c^* satisfies $p_0(c^*, F) = p_1(c^*, F)[1 - F(p_1(c^*, F))]$ and makes the seller indifferent between deterring and inducing the consumer's learning, when the designer chooses the fully informative signal (whose distribution of posterior means is F).

Theorem 1. *If $c \geq c^*$, among all signals, the fully informative signal maximizes consumer surplus and total surplus, and it minimizes the seller's revenue. In equilibrium, the consumer does not acquire information.*

Proof. Fix any $c \geq c^*$; that is, the consumer does not acquire information under the fully informative signal σ^*. Take an arbitrary signal σ, and let G denote the distribution of posterior means under σ. It holds that F is a mean-preserving spread of G. I show $p_0(F) \leq p_0(G)$. Indeed, $x_0(F)$ and $x_0(G)$ satisfy $c = \int_0^{x_0(F)} F(x)dx = \int_0^{x_0(G)} G(x)dx$. Because F is a mean-preserving spread of G, $\int_0^x F(v)dv \geq \int_0^x G(v)dv$ for any $x \geq 0$. Thus, $x_0(F) \leq x_0(G)$, which implies $p_0(F) = \min(x_0(F), \mu) \leq \min(x_0(G), \mu) = p_0(G)$.

There are two cases to consider. If the consumer does not acquire information under σ, the consumer is better off under σ^* because $\mu - p_0(F) \geq \mu - p_0(G)$. Similarly, the seller's payoff is lower under F. Second, suppose that the consumer acquires information under σ. Then, we obtain $\mu - p_0(F) \geq \mu - p_0(G) \geq \int_{p_1(G)}^{+\infty} x dG(x) - p_1(G)[1 - G(p_1(G))]$. The last inequality holds because the total surplus is lower but revenue is strictly higher when the seller charges $p_1(G)$ instead of $p_0(G)$. Because the last expression is the consumer's payoff under σ, the consumer obtains a greater payoff under σ^*. In contrast, the seller's payoff is lower under F as $p_0(F) \leq p_0(G) < p_1(G)[1 - G(p_1(G))]$. Finally, σ^* maximizes total surplus because trade occurs with probability 1 and the consumer does not incur information acquisition cost. □

The results have a novel implication on how the availability of product information affects consumer welfare: *The mere availability of product information can benefit consumers even if they do not acquire it.* To see this, suppose that consumers have access to new information sources such as customer review websites, which enable them to acquire more accurate information about products and services. How does the new source of information benefit consumers? A typical argument would be that they can more accurately check whether their valuations exceed prices; alternatively, we might argue that the information could change the distribution of consumers' willingness to pay in a way that sellers lower prices. Theorem 1 point to a new benefit: The new information source can benefit consumers because sellers have an incentive to lower prices to discourage consumers from learning the new information.

Note that Theorem 1 is vacuous for a sufficiently large c: For example, if c is greater than the highest possible value, any signals give the consumer a payoff of zero, and thus the fully informative signal trivially maximizes consumer surplus. I do not establish any quantitative results regarding how small the cost can be for Theorem 1 to apply. However, the following example suggests that the cost might not need to be extremely high.

Example 1. Suppose that v is uniformly distributed on $[0, 1]$. If $c = 0$, the consumer's payoff is maximized by partial disclosure (Roesler and Szentes, 2017). In contrast, if $c \geq c^* = 1/32 \approx 0.03$, the consumer's payoff is maximized by full disclosure. (See Footnote 6 for the details.) Although full disclosure is not a unique consumer-optimal signal, it is not hard to find a natural class of signals that singles out full disclosure as a unique optimum. For instance, given any $\eta \in [0, 1]$, consider a *truth-or-noise* signal σ_η that sends $s = v$ with probability η and $s = z$ with probability $1 - \eta$, where z is an independent draw from $U[0, 1]$. If c is close to c^*, among the truth-or-noise signals, full disclosure ($\eta = 1$) uniquely maximizes consumer surplus, because $\int_0^z G_\eta(x)dx$ decreases in η for any $z \leq 1/2$ and thus it leads to a higher price $p_1(G_\eta)$. Here, G_η is the distribution of posterior expectations given η.

Next, I establish a more general comparative statics on valuation distributions. Formally, given c, let $\mathcal{N}(c)$ denote the set of distributions under which the seller deters learning:

$$\mathcal{N}(c) := \{G : p_0(c, G) \geq p_1(c, G)[1 - G(p_1(c, G))]\}.$$

Precisely, $\mathcal{N}(c)$ is the set of distributions of posterior means such that the consumer does not acquire information in equilibrium. Different G and H in $\mathcal{N}(c)$ might come from different valuation distributions or signals, but this distinction does not matter.

It would be difficult to explicitly characterize distributions in $\mathcal{N}(c)$. However, it is relatively easy to find (c, G) such that the comparative statics around G is relevant. Indeed, for any distribution G satisfying Assumption 1 in the next section, $p_0(c, G) > p_1(c, G)[1 - F(p_1(c, G))]$ holds for a sufficiently high $c < x_0^{-1}(\mu)$. Then, given such c, any H sufficiently close to G belongs to $\mathcal{N}(c)$.

Proposition 2. *Take any $c > 0$ and two distributions $G, H \in \mathcal{N}(c)$ of the consumer's posterior expectations. If G second-order stochastically dominates H, the seller sets a higher price and obtains a higher payoff under G than H.*

Intuitively, as long as the stochastic shift does not induce the consumer to acquire information, the seller can charge a higher price because his willingness to pay (i.e., the ex ante expected value) weakly increases. Furthermore, the consumer indeed has less incentive to acquire information under a second-order stochastically larger distribution, because the value of information under G,

$$\int_0^{+\infty} \max(x-p,0)dG(x) - (\mu - p) = \int_0^{+\infty} \max(0, p-x)dG(x),$$

is smaller than the one evaluated at H. (Note that $\max(0, p-v)$ is a decreasing convex function of v.) Thus, the seller can raise a price without worrying about inducing the consumer's learning.

5 Information Acquisition Costs Benefit Consumer

In this section, I fix the distribution G of posterior means and consider comparative statics in the cost c of information acquisition. Figure 1 depicts the consumers' equilibrium payoff as a function of c when G is the uniform distribution on $[0,1]$.[6] While the consumer's payoff decreases in c below and above $c^* = 1/32$, it jumps discontinuously at $c^* = 1/32$, at which the consumer surplus is globally maximized. I show that this is true under the following assumption.

Assumption 1. $G(p^M) > 0$, where $p^M := \min(\arg\max_p p[1-G(p)])$ is the lowest monopoly price under G.

Theorem 2. *Consider any F and σ such that the corresponding distribution of posterior means G satisfies Assumption 1. Then, c^* in equation (3) is positive and uniquely maximizes consumer surplus among all $c \geq 0$. Also, c^* maximizes total surplus and minimizes the seller's revenue. At c^*, the consumer does not acquire information in equilibrium.*

Proof. I show that c^* in Proposition 1 maximizes both consumer and total surplus. First, $c^* > 0$ because Assumption 1 implies $p_0(0) = x_0(0) < p_1(0)[1-G(p_1(0))]$. Corollary 1 implies that the consumer's payoff is decreasing in c on $[c^*, +\infty)$. Now, define $\hat{c} := \min\left(\arg\max_{c \in [0,c^*]} \int_{p_1(c)}^{+\infty} 1 - G(x)dx - c\right)$. If $\hat{c} = c^*$, the proof is done. Suppose $\hat{c} < c^*$. To prove that c^* globally maximizes the consumer's

[6] Direct calculations show that the consumer's equilibrium payoff is $1/8 - s$ if $c < c^* = 1/32$, $1/2 - \sqrt{2s}$ if $s \in [1/32, 1/8]$, and 0 if $s \geq 1/8$.

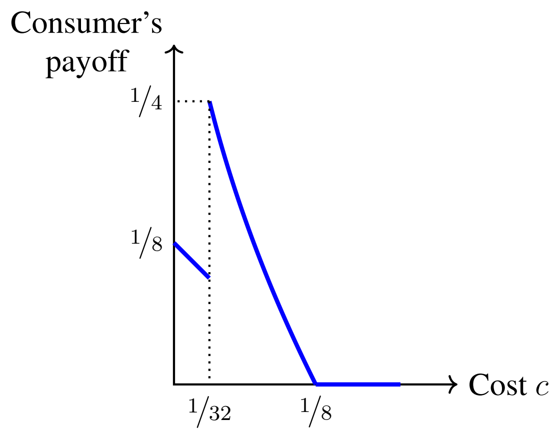

Figure 1: Consumer surplus when $G = U[0, 1]$

equilibrium payoff, it is enough to show that the consumer's payoff is strictly greater at $c = c^*$ than at $c = \hat{c}$. Suppose that the cost increases from $c = \hat{c}$ to $s = c^*$. The seller's payoff weakly decreases, i.e., $p_1(c^*)[1 - G(p_1(c^*))] \leq p_1(\hat{c})[1 - G(p_1(\hat{c}))]$, because the seller under c^* chooses a price from a smaller set. (See Lemma 2.) However, total surplus strictly increases, because trade is more likely occur and the consumer does not pay the cost at $c = c^*$. Therefore, the consumer is strictly better off at c^* than $\hat{c}$.

Next, c^* maximizes total surplus because the consumer purchases the product with probability 1 and does not incur the information acquisition cost.

Finally, the seller's revenue is minimized at c^*, because it is weakly decreasing in c on $[0, c^*)$, increasing on $[c^*, +\infty)$, and continuous at everywhere. □

Theorem 2 might look similar to the finding of Roesler and Szentes (2017), which shows that a consumer can benefit from being partially ignorant of his valuation.[7] However, they are different: In their work, the seller best responds to the consumer's information acquisition policy. In this paper, the consumer decides whether to learn product value best responding to the price set by the seller. What drives Theorem 2 is the consumer's ability to acquire information relatively cheaply but not freely, and not the fact that he is ignorant of his valuation.

[7] In a different context, Kessler (1998) finds that the agent could benefit from not being informed of his type in a principal-agent model.

6 Conclusion

The paper identifies the consumer-optimal information disclosure in the context of a monopoly pricing with costly information acquisition. The main takeaway is that the "threat" to acquire information can benefit the consumer indirectly through low prices. When it is costly for the consumer to observe a noisy signal of his valuations, the fully informative signal could maximize consumer surplus because the seller lowers a price to deter learning. For a wide range of signal structures, consumer surplus is maximized at a positive level of information acquisition cost.

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