# Product Line Design with Frictions*

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**Abstract**

We study a monopolist's product line design problem with search frictions. Consumers only evaluate a random subset of price-quality pairs in the menu, limiting the monopolist's ability to perfectly match contracts to consumer types. This creates a tradeoff faced when expanding the product line between extracting more rents from different consumer types and increased search costs. We show that when consumers are limited to seeing a single random contract out of the menu, then the optimal menu for the monopolist always contains a single offer. When consumers observe more than one offer, we show that a balanced menu with two contracts that are seen by a consumer with the same probability is never optimal. The monopolist rather has an incentive to "bias" the menu so that one of the offers is observed more often. Using an unbalanced menu has an impact on the quality provided to low valuation consumers, either reinforcing or reducing the distortions generated by asymmetric information. We discuss the consequences on quality provision, as well as the welfare effects of these distortions.

JEL codes: D82, D83, L15

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# 1 Introduction

Consumers are exposed to multiple products, brands, and prices. The consumer's decision problem is a complex process (Gilboa et al. (2021)) demanding both time and cognitive resources for the evaluation of the various alternatives. Recent empirical evidence (e.g., Sovinsky Goeree (2008), Honka and Chintagunta (2017), Honka et al. (2017), Honka et al. (2019),Abaluck and Adams-Prassl (2021), and Aguiar et al. (2023)) suggest that consumers often fail to consider all options during their purchase decisions, and that this behavior has consequences in both terms of estimation and policy evaluations.

Technological advancements have allowed sellers to use complex algorithms and marketing strategies in the pursuit of higher profits. However, consumers' behavioral responses to these complex strategies could limit their success, and reshape the incentives of sellers to adjust their strategies to better adapt to consumers' limitations.

Our goal is to present a simple model that captures the basic trade-off between expanding the product line to extract more rents from different types of consumers and the increasing complexity that a larger product line involves. We consider a setting in which sellers have limited control over the matching between consumers and offers, while consumers face frictions in the interaction with the seller, and remain uninformed about the specifics of his product line.

We propose a framework to study how a monopolist will determine his product line when consumers are unaware of all the alternatives they have available. We do so by introducing search frictions in a canonical price discrimination setting à la Mussa and Rosen (1978). We model search frictions as random samples obtained by the consumers about the products they have available. This provides a novel application of "sampling" (e.g., Dhangwatnotai et al. (2015), Fu et al. (2021)) for the consumer's problem, and allows us to study how within-firm search shapes the incentives of the firm.

In our model, a monopolist produces a vertically differentiated good for a continuum of consumers. Consumers have single unit demands and heterogeneous valuations for quality. The monopolist designs a menu of quality-price pairs in order to maximize his expected profits. Consumers are unaware of the items available in the menu due to limitations in their processing capacity or search frictions, and must draw offers from the monopolist's menu uniformly at random. Sampling is costless but there is a exogenous sample size that determines the number of offers consumers will be able to observe. In the baseline model, there is no heterogeneity in the number of samples each consumer has.

We find that if consumers cannot observe more than a single offer from the menu then the monopolist designs a menu with a single option. That is, when frictions are severe, the seller is better off removing all variety and uncertainty from the menu, offering only one version of his product for all consumers to consider. When frictions are less severe and consumers could observe more than one offer, we show that the optimal menu cannot contain only two offers in the same proportion, if it contains only two offers it must always be unbalanced: the monopolist has an incentive to "bias" the composition of the menu so that one of the offers is sampled (observed) more often than the other. In turn, having an unbalanced menu has an impact on the quality provided to low valuation consumers, either reinforcing or reducing the distortions generated by asymmetric information in this setting.

In the case of a single sample, the optimality of a single offer comes from having consumers being unable to compare two different offers, regardless of the structure of the menu. This implies that no incentive compatibility type constraint will be relevant for the seller, and only participation constraints could be binding and determine the structure of the optimal offers. This is no longer true once consumers obtain more than one draw from the menu, as now there is a chance they would be able to compare two different offers if these are part of the menu. This makes incentive compatible constraints relevant again, and modifies the structure of the optimal menu. However, having a noisy match between offers and consumers with different valuations changes the distortions that the optimal menu will exhibit, as either lower or bigger distortions on the quality provided to low types could arise in this case. Since there is a possibility of having consumers observing only one offer at a time, there is an extra incentive to increase the sampling probability of the most profitable offer, further distorting the composition of the optimal menu.

## Related Literature

Our work is inspired by the literature studying complexity in mechanism design problems (e.g., Babaioff et al. (2018), Bergemann et al. (2021), Daskalakis and Zampetakis (2020), Dhangwatnotai et al. (2015), Fu et al. (2021), Hart and Nisan (2017, 2019)). Some papers in this literature study problems in which the designer does not have a prior defined over some unknown characteristic of the environment but can rely on samples to improve his designs. We depart from this literature by assuming agents (consumers) are uninformed about an attribute of the mechanism (the offers) and they must rely on samples to make their decisions instead of the designer (monopolist).

Our work contributes to the literature of product line design and adverse selection (e.g., Mussa and Rosen (1978)) by introducing search frictions. Recent interest in competitive models within this framework has grown (e.g., Garrett et al. (2018), Lester et al. (2019), and Fabra and Montero (2022)). However, these studies focus on search frictions occurring between firms, as a form of imperfect competition, while ignoring any frictions within the product lines of each firm. In contrast, our model explores the problem of a monopolist with search occurring within his own product line due to having consumers unaware of the composition of his product line. Nocke and Rey (2023) also studies a model with within-firm search but in a different setting where products characteristics are fixed, optimal pricing is uniform, and search is sequential. They focus on the different type of equilibria in terms of products positioning. In our model, both products characteristics (quality) and their prices are endogenous, search is simultaneous, and non-uniform pricing could be profitable.

Our model is also related to the literature introducing information design into mechanism design problems (e.g., Krähmer (2020), Mensch (2022), Bergemann et al. (2022), Doval and Skreta (2022), and Cusumano et al. (2023)). However, in these models consumers must acquire information about their valuations but there are no frictions in the offering of the seller(s). Instead, in our model consumers face no uncertainty about their valuations, and frictions come from the lack of information about the alternatives offered by the seller.

Consumers' behavior in our framework is motivated by complexity concerns. As in Safonov (2022), agents are boundedly rational and sample uniformly at random from an unobservable menu. While Safonov (2022) focuses on the complexity of the decision rule used by agents, we focus on the design problem faced by the seller and take the behavior of agents as fixed.

An alternative equilibrium concept using samples have been proposed previously by Osborne and Rubinstein (1998) and Osborne and Rubinstein (2003). Spiegler (2006) uses this equilibrium notion to study a similar setting to ours, albeit in a competitive environment where agents are aware of the alternatives they have but face uncertainty about the values those options would have for them. In our setting, agents remain unaware of the options they have available but face no uncertainty on the value those options have once revealed available. This makes our framework closer to the environment in Carroll (2015) which studies a moral hazard problem in which the principal must design a incentive scheme but is unaware of the set of actions the agent has available. However, in our model are the agents (consumer) who are unaware of options available instead of the principal.

Similar to Doval and Skreta (2022), Bergemann et al. (2022), and Sandmann (2023), the optimal menu in our setting could contain a single offer even in cases where the standard Mussa and Rosen (1978) solution involves a offering a complete product line. Our contribution to this literature lies on providing search frictions as a new rational for the reduction on the product variety.

Our model is also closely related to classic models of price discrimination as Varian (1980) and Burdett and Judd (1983) in which consumers vary in the number of offers they observe. However, our framework includes asymmetric information and a single firm with an unknown menu instead of having multiple firms competing in an environment without taste heterogeneity. We also depart from this classic models by providing a non-necessarily fully rational interpretation of this phenomenon.

### Outline

Section 2 describes the baseline model. Section 3 discusses some benchmarks. Section 4 characterizes the solution to the problem with a single sample. Section 5 discusses the problem with two or more samples. Section 6 discusses some extensions. Finally, Section 7 concludes.

## 2 Model

We consider the problem of a monopolist (or seller) producing a vertically differentiated good interacting with a unit measure of consumers. Consumers have single unit demands and heterogeneous valuations for quality. A fraction $\mu_l \in [0,1]$ of consumers have low valuation ($\theta_l > 0$) per unit of quality, while a fraction $\mu_h = 1 - \mu_l$ have high valuation ($\theta_h > \theta_l$). If a consumer with valuation $\theta$ purchases a good of quality $q$ and price $p$, then his utility is

$$\theta q - p.$$

The monopolist's per-unit profits from selling a good of quality $q$ at price $p$ is

$$p - \phi(q)$$

where $\phi(q)$ is the per-unit cost of producing a good of quality $q$. We assume the cost function $\phi$ is twice continuously differentiable, strictly increasing, strictly convex, and satisfies $\phi(0) = \phi'(0) = 0$ and $\lim_{q\to\infty} \phi'(q) = \infty$.

The monopolist's problem consists of designing a menu of quality-price pairs (or offers) in order to maximize his expected profits. Consumers' valuations are private information, hence the seller cannot condition the offers in the menu to the valuation of the consumers. However, the seller could still try to screen different types of consumers by designing offers tailored to their particular characteristics (here, their valuations). We depart from the traditional model by introducing a friction in the interaction between the monopolist and consumers. We assume consumers are unable to observe nor conjecture what is on the menu offered by the seller. Instead, they have access to *samples* that could reveal some of the products available for purchase. Sampling is costless for consumers but they are endowed with an exogenous sample size $n$ that determines how many (potentially identical) offers they could draw. In each draw the menu is held fixed, i.e., sampling is with replacement. Then, if the monopolist offers a menu $M = \{(q_1, p_1), (q_2, p_2), ..., (q_m, p_m)\}$ with $m$ offers, each consumer would obtain $n$ samples drawn uniformly at random from the menu $M$. On each draw, each offer will be observed with probability $\frac{1}{m}$ by consumers. Since the menu is held fixed on each draw, the monopolist is unable to condition offers to consumer's history of samples.

We do not rule out the possibility of having repeated offers in our framework. Typically, such repeated offers have no impact on the outcomes obtained by the seller or buyers. However, in our framework this is not usually the case, and having repeated offers indeed could change the product a buyer will ultimately purchase. This has two direct consequences on our model: first, while repeating only some offers has an impact on the outcome of the interaction between the seller and buyers, duplicating all of them does not. Hence, a natural multiplicity will arise in any of our results if we do not impose an extra constraint. Therefore, we will focus on menus with minimal size. The second is that the number of copies of each offer to include in the menu must be optimally chosen the monopolist. This could bring an existence problem as finite size menus could not be enough to implement the monopolist's desired policy. We rule out this problem by imposing a limit $\overline{m}$ on the maximum size a menu could achieve. We focus on the case in which $\overline{m}$ is large.[1]

Another source of equilibrium multiplicity is indifference between different offers ei-

[1]Having the limit $\overline{m}$ allows us to "reach" the best possible approximation to the desired policy if such policy involves having a non-rational fraction associated with a particular offer.

ther by consumers or the monopolist. We impose the following assumption to rule out these cases.

**Assumption 1** (Tie breaking rules)**.** *If a consumer is indifferent between two or more offers, she breaks ties in favor of one of the offers generating the highest profits among them. If the monopolist is indifferent between two or more menus, then he breaks ties in favor of the consumers, choosing the menu that gives higher utility to consumers.*

**Discussion**

The frictions in our model allow a few different interpretations. The most direct being a model of search or informational frictions as in the random sample size model in Burdett and Judd (1983). A key difference however comes from the fact that in our model the probabilities are not completely exogenous, as the seller could influence them by adjusting his product line.

Our model also allows an alternative behavioral or bounded-rationality interpretation. Within this interpretation, sampling is used to capture how the limitations in consumers processing capacities could limit the number of offers they are able to evaluate. Then, the frictions in our model could be interpreted as a form of model misspecification, in which consumers held an incorrect model of the monopolist design problem: consumers assume the complete product line offered by the seller is given by the samples they observe. Another source of these frictions could be inattention: while consumers are exposed to all offers, only some of them capture their attention.

Finally, a more suitable interpretation is with respect to advertising. In particular, frictions in our model could be the outcome of the allocation of a given advertisement budget or resources to different products to change their consideration probability. It could also come from how allocating products in a set of different fixed "slots" (e.g., different aisles of a retail store or website space in a digital platform) could change consumer's consideration of them. In relation to this, Nocke and Rey (2023) also considered a setting in which the seller could allocate different products in a fixed set of slots. However, in their setting there is no price discrimination in equilibrium as it is optimal to charge the same price for each product. Villas-Boas (2004) and Eliaz and Spiegler (2011) consider instead settings in which advertisement is costly but where the design dimension is further restricted.

# 3 Benchmarks

In this section we analyze the original framework of Mussa and Rosen (1978) in which consumers observe the complete menu offered by the monopolist. We will refer to this case as the *full-consideration* environment, and characterize both the efficient symmetric-information menu, and the profit maximizing optimal menu under asymmetric information.

## 3.1 Efficient Allocation Under Full Consideration

We start with the efficient or full-information case in which the monopolist could perfectly identify different type of consumers, offering personalized contracts to each of them.

Here the efficient allocation involves providing to each type of consumer a good with quality that maximizes the surplus he generates, i.e., to provide to a consumer with valuation $\theta_i$, quality $q_i^*$ such that

$$q_i^* = \arg\max_q \theta_i q - \phi(q).$$

This implies that the quality provided to each type of consumer is defined by the optimality condition

$$\phi'(q_i^*) = \theta_i.$$

We denote the surplus generated by each of these offers by

$$S_i^* = \theta_i q_i^* - \phi(q_i^*).$$

If the monopolist has full-information, he could charge a price that captures all the utility that a good of quality $q_i^*$ generates for a consumer with valuation $\theta_i$, i.e., $p = \theta_i q_i^*$. That is, the monopolist will offer to each consumer of type $\theta_i$, a contract $(q_i^*, \theta_i q_i^*)$, capturing the full surplus $S_i^*$ as his profits from this consumer.

## 3.2 Mussa-Rosen menu

We now turn to the profit maximizing problem under full-consideration and asymmetric information.

The efficient allocation above is no longer implementable as the monopolist cannot identify the valuation of each consumer directly. Instead, the monopolist must rely on a menu that screen consumers based on their preferences.

It is well known that the solution involves offering to high valuation consumers a product at the efficient quality level, $q_h^{mr} = q_h^*$, while distorting the quality provided to low valuation consumers, $q_l^{mr} < q_l^*$. In particular, the quality provided to the low type is implicitly defined by

$$\phi'(q_l^{mr}) = \theta_l - \frac{\mu_h}{\mu_l}(\theta_h - \theta_l)$$

if the right hand side expression is positive, and $q_l^{mr} = 0$ if it is not the case. Prices are defined by the incentive compatibility constraint of the high type and the participation constraint of the low type respectively:

$$p_h^{mr} = \theta_h q_h^{mr} - (\theta_h - \theta_l) q_l^{mr}$$

$$p_l^{mr} = \theta_l q_l^{mr}.$$

Note that if $q_l^{mr} = 0$ then $p_h^{mr} = \theta_h q_h^{mr}$ which implies the seller captures all the surplus generated by high valuation consumers. Note that also in this case $p_l^{mr} = 0$, so low valuation consumers are receiving an offer $(0, 0)$, obtaining zero utility as well. We interpret this zero-quality, zero-price offer $(0, 0)$ as low valuation consumers not being served in this case, i.e., they are excluded from the market. While in this case considering the offer $(0, 0)$ an actual product or not makes no difference in terms of profits, it would make a difference in our model with partial consideration, as search frictions will be impacted by including or excluding this offer from the menu.

We will refer to the menu with $q_l^{mr} > 0$ as the *Mussa-Rosen menu with two offers* and the menu with $q_l^{mr} = 0$ as the *Mussa-Rosen menu with a single offer*.

# 4 Optimal Menu with a Single Sample

In this section we analyze the monopolist's problem when consumers draw a single sample from the menu, i.e., when they cannot observe more than one offer. We start by discussing the performance of the Mussa-Rosen menu in this context. Then, we characterize the optimal menu and compare it to the Mussa-Rosen solution. Finally, we provide some comparative statics with respect to the fraction of high valuation consumers, and discuss the effects over quality provision and welfare.

## 4.1 Mussa-Rosen menus with a single sample

Consider first the case of $\mu_h \geq \frac{\theta_l}{\theta_h}$. In this case, the Mussa-Rosen menu with a single offer is optimal, offering only the contract $(q_h^*, \theta_h q_h^*)$. Clearly, this menu is implementable with a single sample as offering a menu with only $(q_h^*, \theta_h q_h^*)$ guarantees that such offer will be observed by consumers with probability one. Thus, in this case the solution with a single sample and full-consideration coincide.

For $\mu_h < \frac{\theta_l}{\theta_h}$ this is no longer the case: the Mussa-Rosen menu involves using two different offers to screen consumers but this cannot be perfectly replicated in the single sample case as we discuss below.

Starting with the Mussa-Rosen menu with two offers described in the previous section. Is it optimal to offer some variation of this model if there is a single sample? The answer is (generically) negative: any menu with two or more offers is dominated by a menu with a single offer.

Note that since the Mussa-Rosen menu contains two different offers in this case, each one of them is drawn with probability $\frac{1}{2}$ when consumers draw only one sample. By design, when a consumer draws an offer designed for his type, he always accepts such offer. If a high valuation consumer draws the offer designed for the low valuation consumer he still purchases it since both offers give him the same utility level by design. However, if a low valuation consumer draws the offer designed for the high valuation consumer, he refuses to purchase from the monopolist. Then, due to this informational friction, there is a chance that some consumers refuse to purchase from the monopolist despite all consumers always purchase from the monopolist under full-consideration.

Consider first the case in which the fraction of high valuation consumers is very small (i.e., a value of $\mu_h$ close to zero). Note that under the Mussa-Rosen menu half of the time consumers draw an offer intended for the high type, but this offer is accepted only by a very small fraction of consumers. The other half of the time, consumers receive a low quality offer at a distorted quality level: the quality is below what would be efficient for low types. This offer is always accepted. Compare this menu with an alternative menu that contains only the efficient low quality contract $(q_l^*, \theta_l q_l^*)$. Note this offer is also accepted by all consumers and generates strictly larger profits from low types compared to the distorted offer in the Mussa-Rosen menu, but it generates lower profits from high valuation consumers that received a high quality offer before. For $\mu_h$ close to zero this last negative effect is negligible, so the positive effect dominates. This makes the original Mussa-Rosen menu suboptimal in this case.

Now consider a fraction of high valuation buyers close but strictly below the critical value $\frac{\theta_l}{\theta_h}$. Here, the profits of the Mussa-Rosen menu with two offers and one offer are very close to each other, i.e., there is little loss on excluding the low types from the market. On the other hand, including the low quality offer in the menu has the risk of losing profits by deviating high valuation consumers to this offer which generates lower profits for the monopolist since there is a fifty percent chance that a high valuation consumer observes only the low quality offer. If the fraction of high valuation consumers is big enough, then this second effect dominates the loses from excluding the low valuation consumers from the market. This makes offering only the high quality product and price it according to the high valuation consumers' willingness to pay more attractive.

## 4.2 Optimal menu

We have shown that the standard Mussa-Rosen menu is not optimal in general. The question that still remains is whether there are other "screening" menus with more than one offer that perform better in the case of a single sample. Our main result shows that this is not the case, and any screening menu is dominated by a menu with a single option.

There are two very simple steps that show that there is no better menu available for the monopolist. First, since each consumer will always observe a single offer, there are no incentive compatibility constraints to consider when designing the structure of a particular offer. Hence, only participation participation constraints will determine the form of each contract. This means that any offer which is part of an optimal menu must have a very simple form: its quality must match the efficient quality for the lowest type accepting such offer and its price will be determined by the participation constraint of that specific type, extracting all the consumer surplus generated for that type. The second step involves showing that then the monopolist's problem could be written as a linear program over the offers of this simple form, and that among those offers there will be one that generates higher profits for the monopolist.

**Theorem 1.** *Consider the problem with a single sample. Under Assumption 1, the optimal menu contains a single offer. Moreover, this offer takes the form $(q_i^*, \theta_i q_i^*)$ for some type $\theta_i$.*

*Proof.* Consider an offer $(\hat{q}, \hat{p})$ part of an optimal menu. Suppose $\hat{\theta}$ is the lowest accepting this offer but $\hat{\theta}\hat{q} - \hat{p} > 0$. Then, by increasing the price up to $\hat{\theta}\hat{q}$ this offer is still accepted by all types $\theta > \hat{\theta}$, and the incentives of all other offers remain the same. Hence, in order for $(\hat{q}, \hat{p})$ to be part of an optimal menu, it must be the case that $\hat{p} = \hat{\theta}\hat{q}$, where $\hat{\theta}$ is the lowest type accepting this offer. Then, any offer from an optimal menu must satisfy this property.

Again, as the structure of a particular offer has no influence on the incentives generated by all the other offers, it must be the case that the quality in an offer accepted by all types above $\theta_i$ maximizes

$$\theta_i q - \phi(q).$$

This is maximized at the efficient quality level for type $\theta_i$, i.e., $q_i^*$. Hence, any offer part of an optimal menu must have the form $(q_i^*, \theta_i q_i^*)$.

Then, in the case of two valuations, it suffices to compare the profits of a menu only containing $(q_l^*, \theta_l q_l^*)$ and a menu containing only $(q_h^*, \theta_h q_h^*)$ to determine which one is optimal. In the first case, all types of buyers accept the offer, generating profits equal to $\theta_l q_l^* - \phi(q_l^*)$, while in the later, only high valuation buyers accept the offer with associated profits $\mu_h \left(\theta_h q_h^* - \phi(q_h^*)\right)$. Comparing both expressions, we obtain that the first offer is strictly preferred if $\theta_l q_l^* - \phi(q_l^*) > \mu_h \left(\theta_h q_h^* - \phi(q_h^*)\right)$ and the second if $\theta_l q_l^* - \phi(q_l^*) < \mu_h \left(\theta_h q_h^* - \phi(q_h^*)\right)$. Finally, if $\theta_l q_l^* - \phi(q_l^*) = \mu_h \left(\theta_h q_h^* - \phi(q_h^*)\right)$, then the monopolist is indifferent between using any of the two offers, in any proportion, as both generate the same profits. But high valuation consumers strictly prefer offer $(q_l^*, \theta_l q_l^*)$ as the obtain strictly positive utility from this it, instead of zero under $(q_h^*, \theta_h q_h^*)$. Hence, by Assumption 1 offering only $(q_l^*, \theta_l q_l^*)$ is optimal.

□

In the next section we further characterize the form of the solution and provide comparative statics with respect to the fraction of high valuation consumers.

## 4.3 Comparative statics

Here we study the effects that changes in the fraction of high valuation consumers have on the optimal menu and its outcomes. We also compare the outcomes of the optimal menu with the outcomes under full-consideration.

#### Changes in the fraction of high valuation consumers $\mu_h$

As the discussion of the suboptimality of the Mussa-Rosen menu with two offers suggests, depending on the fraction of high valuation consumers either offering only the efficient low quality offer or only the efficient high quality offer is optimal for the monopolist. The following proposition shows that this relation is monotone: there is a threshold

$\hat{\mu}_1$ such that if the fraction of high valuation consumers is below $\hat{\mu}_1$ then it is optimal to provide only the low quality product, while if it is above $\hat{\mu}_1$ then it is optimal to offer only the high quality product.

**Proposition 1.** *Fix the valuations $\theta_l$ and $\theta_h$. Under Assumption 1, there is a unique threshold $\hat{\mu}_h^1 \in (0,1)$ such that for $\mu_h > \hat{\mu}_h^1$ the optimal menu contains only the efficient high quality offer $(q_h^*, \theta_h q_h^*)$, while for $\mu_h \le \hat{\mu}_h^1$ the optimal menu contains only the efficient low quality offer $(q_l^*, \theta_l q_l^*)$.*

For $\mu_h = \hat{\mu}_h^1$, both menus, $\{(q_h^*, \theta_h q_h^*)\}$ and $\{(q_l^*, \theta_l q_l^*)\}$, generate exactly the same profits for the seller, and any combination of these two offers also achieves the same level of profits. Hence, the monopolist is indifferent between using any menu containing only these two offers in any proportion, while consumers prefer $(q_l^*, \theta_l q_l^*)$. Assumption 1 requires that only $(q_l^*, \theta_l q_l^*)$ is used in this case.

Moreover, we can compare this with the threshold that determines whether one or two offers is optimal under full-consideration. Let $\mu_h^{mr}$ be this value, i.e., $\mu_h^{mr} = \frac{\theta_l}{\theta_h}$.

**Proposition 2.** $\hat{\mu}_h^1 < \mu_h^{mr}$.

*Proof.* The threshold $\hat{\mu}_h^1$ is defined by

$$\hat{\mu}_h^1 = \frac{\theta_l q_l^* - \phi(q_l^*)}{\theta_h q_h^* - \phi(q_h^*)}.$$

Since, $q = q_h^*$ maximizes $\theta_h q - \phi(q)$, we have $\theta_h q_h^* - \phi(q_h^*) \ge \theta_h q_l^* - \phi(q_l^*)$, and $\theta_h > \theta_l$, we have that,

$$\frac{\theta_l q_l^* - \phi(q_l^*)}{\theta_h q_h^* - \phi(q_h^*)} \le \frac{\theta_l q_l^* - \phi(q_l^*)}{\theta_h q_l^* - \phi(q_l^*)} = \frac{\theta_l}{\theta_h}\left(\frac{q_l^* - \frac{\phi(q_l^*)}{\theta_l}}{q_l^* - \frac{\phi(q_l^*)}{\theta_h}}\right) < \frac{\theta_l}{\theta_h},$$

where the last inequality follows from $q_l^* - \frac{\phi(q_l^*)}{\theta_l} < q_l^* - \frac{\phi(q_l^*)}{\theta_h}$. Thus, $\hat{\mu}_h^1 < \mu_h^{mr}$.

□

### Quality comparison

Compared to the Mussa-Rosen menu, the optimal menu with a single sample provides weakly less average quality

**Corollary 1.** *Suppose the cost function takes the form $\phi(q) = \frac{q^2}{2}$. Then,*

- *The average quality provided under the Mussa-Rosen menu is $\theta_l$ if $\mu_h \leq \mu_h^{mr}$, and it is $\mu_h\theta_h$ if $\mu_h > \mu_h^{mr}$.*

- *The average quality provided under the optimal menu with a single sample is $\theta_l$ if $\mu_h \leq \hat{\mu}_h^1$ and $\mu_h\theta_h$ if $\mu_h > \hat{\mu}_h^1$.*

*Then, the average quality provided in the optimal menu with a single sample is weakly lower than the quality provided under the Mussa-Rosen menu under full-consideration. Moreover, the relation is strict for $\mu_h \in (\hat{\mu}_h^1, \mu_h^{mr})$.*

**Welfare comparison**

In terms of welfare, the optimal menu with a single sample induces a weakly lower total surplus. Profits are lower, but consumer surplus could be either equal or bigger than in the Mussa-Rosen menu. Also, the consumer surplus is discontinuous as the optimal menu involves jumping from the low quality to the high quality contract

**Corollary 2.** *Suppose the cost function takes the form $\phi(q) = \frac{q^2}{2}$. Under Assumption 1, in the optimal menu with a single sample:*

- *The total welfare is weakly lower than under full-consideration.*

- *The monopolist's profits are weakly lower than under full-consideration.*

- *Consumer surplus could be equal, lower, or larger than under full-consideration.*

*Moreover, the first two relations are strict if and only if $\mu_h < \mu_h^{mr}$ while the consumer surplus is strictly larger for $\mu_h \leq \hat{\mu}_h^1$, strictly lower for $\mu_h \in \left(\hat{\mu}_h^1, \mu_h^{mr}\right)$, and equal for $\mu_h \geq \mu_h^{mr}$.*

# 5 Two or More Samples

In this section we analyze the case with two or more samples. Now, as consumers could observe more than one offer, two different offers will be compared with positive probability. Hence, the incentive compatibility constraints become relevant in this case.

One of the challenges is that since consumers cannot observe the menu offered by the monopolist, we cannot use a revelation principle argument to reduce a priori the size of the optimal menu, nor the number of differentiated offers the optimal menu could contain. Instead, our approach to solving the problem with more than one sample involves characterizing structural features that the optimal menu must exhibit.

The following definition describes the type of menus we will be looking for in this case.

**Definition 1.** *A menu exhibits screening if it contains at least two offers $(q_l, p_l)$ and $(q_h, p_h)$ such that*

- *$(q_l, p_l)$ is accepted by all consumers,*
- *$(q_h, p_h)$ is accepted only by high valuation consumers, and*
- *$(q_h, p_h)$ is preferred over $(q_l, p_l)$ by high valuation consumers.*

We first identify one common characteristic that any optimal menu must satisfy with respect of the type of offers tailored to high valuation consumers.

**Lemma 1.** *Suppose an offer $(q, p)$ is accepted only by high valuation consumers. If $(q, p)$ is part of an optimal menu, then $q = q_h^*$.*

*Proof.* By contradiction, suppose $q \neq q_h^*$. Consider the following offer: $q' = q_h^*$ and $p' = p + \theta_h(q_h^* - q)$. High valuation consumers are indifferent between $(q, p)$ and $(q', p')$, but replacing $(q, p)$ by $(q', p')$ generates strictly bigger profits for the firm. Hence, $(q, p)$ cannot be part of an optimal menu. $\square$

That is, the optimal menu must exhibit the standard "no distortion at the top" feature when there is more than one sample.

Our next lemma establishes one of the key conditions that an optimal menu with screening must satisfy in this context.

**Lemma 2.** *Consider the problem with two or more samples. Suppose the optimal menu contains only two offers $(q_a, p_a)$ and $(q_b, p_b)$, and the maximum menu size $\overline{m}$ is large. Then, the profits of the menus $\{(q_a, p_a)\}$ and $\{(q_b, p_b)\}$ must be the same.*

*Proof.* Suppose the optimal menu $M^*$ contain only two offers $(q_a, p_a)$. Since the condition in the lemma trivially holds if $(q_a, p_a) = (q_b, p_b)$, we assume $(q_a, p_a) \neq (q_b, p_b)$.

Let $R_a$ and $R_b$ the profits obtained by the seller from buyers who sample only offer $(q_a, p_a)$ and $(q_b, p_b)$ respectively, and $R_{ab}$ the profits obtained by the seller from buyers who sample both offers. Without loss, assume $R_a \geq R_b$.

By contradiction, suppose the profits of menus $\{(q_a, p_a)\}$ and $\{(q_b, p_b)\}$ are different, i.e., $R_a \neq R_b$.

Since $M^*$ is an optimal menu, it must be the case that the profits $R_{ab} > R_a$, otherwise having only $(q_a, p_a)$ would be optimal.

The expected profits under menu $M^*$ are

$$\left(\frac{1}{2}\right)^n R_a + \left(1 - 2\left(\frac{1}{2}\right)^n\right) R_{ab} + \left(\frac{1}{2}\right)^n R_b$$

Fix the offers in $M^*$ and consider a different problem in which the decision variables are the probability of each offer being drawn from this menu. Let $\alpha \in [0,1]$ be the probability that offer $(q_a, p_a)$ is drawn in each sample in this case, while $(1-\alpha)$ will be the probability that offer $(q_b, p_b)$ is drawn in each sample.

We can write the seller's profits in this problem as

$$\alpha^n R_a + (1 - \alpha^n - (1-\alpha)^n)) R_{ab} + (1-\alpha)^n R_b \tag{1}$$

Note that the outcome of menu $M^*$ could be replicated in this environment by setting the probabilities that each offer is drawn to be the same, i.e., $\alpha = \frac{1}{2}$.

Let $\alpha^*$ be the probability that maximizes (1). That is,

$$\alpha^* = \frac{1}{1 + \left(\frac{R_{ab}-R_a}{R_{ab}-R_b}\right)^{\frac{1}{n-1}}}$$

Since $R_a > R_b$, $\alpha^* > \frac{1}{2}$. For $\overline{m}$ large enough, we can find $n \in \mathbb{N}$ and $N \in \mathbb{N}$ such that $n < N$, $N \leq \overline{m}$, and $\frac{n}{N} \in \left(\frac{1}{2}, \alpha^*\right)$. Consider the menu $\hat{M} = \{(q_1, p_1), ..., (q_N, p_N)\}$ containing $N$ offers such that $(q_i, p_i) = (q_a, p_a)$ for $i \leq n$ and $(q_i, p_i) = (q_b, p_b)$ for $i > n$. Then, $\hat{M}$ generates more profits than $M^*$. Hence, $M^*$ cannot be an optimal menu.

□

Lemma 2 shows that a menu with only two offers can be optimal only if the profits of each offer are identical. The intuition behind this result is as follows. Under full-consideration, offering a screening menu, i.e., a menu with two offers in which each type of buyer chooses a different menu entry is costly only in terms of the informational rents that the seller must give the high valuation buyer in order for him to self-select into the right offer. There is no other cost associated with including a second offer in the menu. With sampling, including a second offer induces a a new trade-off or cost: there is a chance of matching buyers to the wrong offer. Starting with a menu with a single offer, there are costs and benefits of including the second offer: some buyers are induced to self-select, which increases seller's profits but also some buyers are now matched to the second offer even when the first offer is more attractive to the seller. If both offers bring the same profits to the seller when buyers are unable to self-select (i.e., if they sample only one of the offers), then it is optimal for the seller to maximize the probability of observing two different offers, i.e., to have both offers in the same proportion. However, if the profits of each offer are different, then there is an incentive to bias the menu towards one of the two offers, and having both offers with the same proportion is no longer optimal.

Next, we impose a restriction of the form of the cost function. This allows us to use the results above to show that the optimal menu cannot have only two offers appearing in the same proportion if consumers have two or more samples.

**Theorem 2.** *Consider the problem with $n > 1$ samples. Suppose the cost function takes the form $\phi(q) = \frac{q^2}{2}$ and the maximum menu size $\overline{m}$ is large enough. Then, the optimal menu never contains only two offers.*

*Proof.* Consider the problem with $n$ samples. By contradiction, suppose the optimal menu $M^*$ contains only two offers. It suffices to search among menus with two offers that exhibit screening, as any other menu with two offers will be dominated by a menu containing a single offer given our assumptions. Moreover, since the menu has only two offers, the price of the low offer will be determined by the participation constraint of low types and the price of the high offer by the incentive compatible constraint of high types. Let $(q_l, \theta_l q_l)$ and $(q_h^*, \theta_h q_h^* - (\theta_h - \theta_l) q_l)$ be these two offers.

Then, the profits under menu $M^*$ could be written as

$$\left(\left(\frac{1}{2}\right)^n + \left(1 - 2\left(\frac{1}{2}\right)^n\right)\mu_l\right)(\theta_l q_l - \phi(q_l)) + \left(1 - \left(\frac{1}{2}\right)^n\right)\mu_h\left(\theta_h q_h^* - (\theta_h - \theta_l)q_l - \phi(q_h^*)\right).$$

In order to this menu to be optimal, the quality for the low type must satisfy the first order condition with respect to the quality of the low offer $q_l$, which could be rearranged as

$$\phi'(q_l) = \theta_l - \frac{\left(1 - \left(\frac{1}{2}\right)^n\right)}{\left(\left(\frac{1}{2}\right)^n + \left(1 - 2\left(\frac{1}{2}\right)^n\right)\mu_l\right)}(\theta_h - \theta_l).$$

From Lemma 2 if $\overline{m}$ is large, for $M^*$ to be optimal we also need

$$\theta_l q_l - \phi(q_l) = \mu_h\left(\theta_h q_h^* - (\theta_h - \theta_l)q_l - \phi(q_h^*)\right).$$

When the cost function takes the form $\phi(q) = \frac{q^2}{2}$, the equations above reduce to

$$q_l = \theta_l - \frac{\left(1 - \left(\frac{1}{2}\right)^n\right)}{\left(\frac{1}{2}\right)^2 + \left(1 - \left(\frac{1}{2}\right)^{n-1}\right)\mu_l}\mu_h(\theta_h - \theta_l)$$

$$\theta_l q_l - \frac{(q_l)^2}{2} = \mu_h\left(\frac{\theta_h^2}{2} - (\theta_h - \theta_l)q_l\right)$$

Generically, the solutions to both equations for $q_l$ are incompatible. Hence, the optimal menu cannot contain only two different offers.

$\square$

While Lemma 2 establishes that two offers can only be optimal if they have the same profits, Theorem 2 shows that the monopolist would never design a product line in which there are only two differentiated offers generating the same profits. Then, if the optimal menu contains only two different offers, the monopolist would offer an unbalanced menu, increasing the proportion of the menu occupied by the most profitable offer. Note that as in the case of full-consideration and the case in which consumers have a single sample, having a single offer could still be optimal in this case and the extra incentive to bias the menu toward one of the offers increases the likelihood of this compared to the full-consideration case.

# 6 Extensions

## 6.1 Heterogeneity in Sample sizes

In our baseline model, we assumed consumers were heterogeneous with respect to their valuations but homogeneous with respect to their sample size. Here we relax this last assumption assuming that consumers can have either one or two samples, and show that the results in Section 5 extend to this setting.

In particular, consider the same environment as in Section 2 but suppose that a fraction $\beta \in (0, 1)$ of consumers obtain two samples, while the remaining fraction $(1 - \beta)$ obtains only one.

First, we show that Lemma 2 could be extended to this setting.

**Lemma 3.** *Consider the problem with heterogeneous sample sizes. Suppose the optimal menu contains only two offers* $(q_a, p_a)$ *and* $(q_b, p_b)$*, and the maximum menu size* $\overline{m}$ *is large. Then, the profits of the menus* $\{(q_a, p_a)\}$ *and* $\{(q_b, p_b)\}$ *must be the same.*

It can be shown that having a mix of buyers with one and two samples does not change the fundamentals of the problem. Indeed, the incentives are very similar to the case in which every buyer has two samples. One difference is that now offering only two offers is even less attractive for the seller: since it is more likely that a buyer samples a unique offer, compared to the case in that everybody has two samples, there are stronger incentives to "bias" the menu further away from the balanced two offers menu.

**Proposition 3.** *Consider the problem with heterogeneous sample sizes. Suppose the cost function is* $\phi(q) = \frac{q^2}{2}$ *and the maximum menu size* $\overline{m}$ *is large enough. Then, the optimal menu never contains only two offers.*

As before, if the optimal menu contains only offers but one of them generates bigger profits for the seller, then bias the menu and sampling toward that offer is optimal for the monopolist. The only difference with respect to the case in which all consumers sample two offers is that now there is an extra chance that a buyer ends up sampling a unique offer, reinforcing the incentives to bias the menu toward that offer. When both offers generate the same profits, again there is no incentives to bias the menu, and it is optimal for the seller to maximize the probability that buyers sample two different offers, i.e., to keep each offer in the same proportion.

## 6.2 More than Two Types and Finite Submenus with a Single Sample

In this section, we extend the results in Section 2 in two directions. First, we show that if there are more than two valuations, then Theorem 1 still holds. Then, building over the environment with more than two valuations, we show that if instead of offering single quality-price pairs over each sample, the seller could offer a small menu of quality-price pairs, he will offer only one of such small menus.

### More than Two Valuations

Now we allow the valuation of the buyer to take more than two different values: $\theta \in \{\theta_1, \theta_2, ..., \theta_N\}$ for some $N > 2$. For each $\theta_i$, we denote by $\mu_i \in (0, 1)$ the proportion of buyers with valuation $\theta_i$. Clearly, $\sum_{i=1}^{N} \mu_i = 1$.

The preferences of the seller and the buyers remain the same as in previous sections: they receive $p - \phi(q)$ and $\theta q - p$ respectively if an offer $(q, p)$ is accepted, and both get zero if the offer is rejected.

Everything else also remains the same: the seller offers a finite menu of quality-price pairs, and buyers sample uniformly at random from such menu.

The main result remains unchanged in this case.

**Assumption 2.** *The expression $\left(\sum_{j \geq i} \mu_j\right) \theta_i q_i^* - \phi(q_i^*)$ has a unique maximizer $i^* \in \{1, ..., N\}$.*

**Proposition 4.** *Consider the problem with more than two valuations and a single sample. Suppose Assumption 2 holds. Then, the optimal menu contains a single offer.*

*Proof.* The proof is a corollary of Theorem 1. The first step remains the same: since there is no incentive compatibility constraint to consider, it is optimal to maximize the surplus of the last type of buyer accepting each offer. Hence, all offers in the optimal menu must have the form $(q_i^*, \theta_i q_i^*)$ for some type $\theta_i$.

Then, the monopolist's profits could be written as

$$\sum_{i=1}^{N} x_i \left(\sum_{j \geq i} \mu_j\right) (\theta_i q_i^* - \phi(q_i^*))$$

where $x_i$ is the fraction of offers of the form $(q_i^*, \theta_i q_i^*)$ including in the menu. Assumption 2 implies that setting $x_i = 1$ for only one of such offers maximizes the profits for the seller. □

Assumption 2 guarantees that a unique offer is preferred, so the solution to the problem is essentially unique.[2] Without Assumption 2 there could be more than one offer that obtains the maximum profits. In this case, the optimal menu could take several forms, since combining all such maximizers in any combination generates the same expected profits for the seller. Hence, while there is always mechanisms that contain a single offer, there will profit maximizing menus that contain different offers as well.[3]

### Collection of menus

We now consider an environment in which the seller could offer more general mechanisms. In particular, we allow the seller to offer a menu each time a buyer draw a new

[2] It's unique if we only consider menus of minimum size, but undetermined without this restriction.

[3] Garrett et al. (2018) avoids this problem by working directly in terms of the utility that the seller and buyers obtain under each offer. However, such transformation doesn't rule out the existence of optimal menus with offers that give buyers a different level of utility.

sample. Formally, a mechanism $\mathcal{M}$ is a collection of menus. Recall that a menu is defined here as a collection of offers or quality-price pairs. Hence, a mechanism is a collection of collections of offers.

Let's consider a simple example for the case of two valuations. Assume $\mu_h < \frac{\theta_l}{\theta_h}$ and let $\mathcal{M}$ be a mechanism which contains only the Mussa-Rosen menu with two offers, i.e.,

$$\mathcal{M} = \{\{(q_l^{mr}, \theta_l q_l^{mr}), (q_h^*, \theta_h q_h^* - (\theta_h - \theta_l) q_l^{mr})\}\}.$$

This is different to a mechanism $\mathcal{M}'$ which contains two menus, each one containing only one of the offers in the Mussa-Rosen menu with two offers:

$$\mathcal{M}' = \{\{(q_l^{mr}, \theta_l q_l^{mr})\}, \{(q_h^*, \theta_h q_h^* - (\theta_h - \theta_l) q_l^{mr})\}\}.$$

Under full-consideration, both mechanisms will generate exactly the same profits as buyers will be able to observe all available options in both cases. Whether they came from the same or different menus has no consequence for buyers in this case. Similarly, if buyers obtain only offers and not menus each time they sample from these mechanisms, then both $\mathcal{M}$ and $\mathcal{M}'$ are equivalent as well, and they generate both the same expected profits for the seller and the same utility for buyers. Hence, in this case the profits are

$$\mu_l \left(\theta_l q_l^{mr} - \phi(q_l^{mr})\right) + \mu_h \left(\theta_h q_h^* - (\theta_h - \theta_l) q_l^{mr} - \phi(q_h^*)\right)$$

However, if buyers are able to observe a menu each time they sample, then the profits of $\mathcal{M}$ and $\mathcal{M}'$ are different: under mechanism $\mathcal{M}$, buyers are always able to self-select into their preferred offer, and the seller obtains the same profits as in the case of full-consideration (with two valuations and two offers). However, under the second mechanism the seller's profits are strictly below the profits he obtains under full-consideration: half of the time buyers only get offer $(q_l^{mr}, \theta_l q_l^{mr})$ in which case all type of buyers accept the offer, and half the time buyers only get offer $(q_h^*, \theta_h q_h^* - (\theta_h - \theta_l) q_l^{mr})$ which only high valuation buyers accept. Therefore, the seller's profits under mechanism $\mathcal{M}'$ are

$$\frac{1}{2} \left(\theta_l q_l^{mr} - \phi(q_l^{mr})\right) + \frac{1}{2} \mu_h \left(\theta_h q_h^* - (\theta_h - \theta_l) q_l^{mr} - \phi(q_h^*)\right).$$

Clearly, with two valuations there is no mechanism that could improve over $\mathcal{M}$ since it is the optimal mechanism under full-consideration, and the profits under full and partial consideration coincide in this case.

Note that without restrictions on the size of the menus, the seller can always obtained exactly the same profits as in the case of full-consideration by including only the optimal menu under full-consideration.

A more interesting question is what happens if each menu cannot contain as many offers as the seller would like to include in the case of full-consideration. For this reason and as we did in the original model, we consider that there is an upper-bound $\overline{m}$ on the size of each menu, and we assume $\overline{m} \leq N$.

Our next result show that even in this environment the seller prefers to include a single menu in the optimal mechanism. In order to obtain this result, we need to introduce a new assumption with the same spirit as Assumption 2.

**Assumption 3.** *There is a unique menu $X^*$ of size up to $\overline{m}$ that maximizes the profits in the case buyers observe the full menu of options.*

**Proposition 5.** *Consider the problem with collection of menus and a single sample. Under Assumption 3 the optimal mechanism contains a single menu.*

*Proof.* Consider a mechanism $\mathcal{M} = \{X_1, X_2, ...\}$, where $X_i = \{(q_1^i, p_1^i), (q_2^i, p_2^i), ...\}$ is a menu with at most $\overline{m}$ entries. Let $\Pi(X_i)$ denote the profits obtained when only menu $X_i$ is observed, and $m_M$ be the size of this mechanism. Then, the expected profits under mechanism $\mathcal{M}$ could be written as

$$\sum_{i=1}^{m_M} \left(\frac{1}{m_M}\right) \cdot \Pi(X_i).$$

Since only one menu $X_i$ is observed each time, there is no cross-menus incentive compatibility constraint to consider. This means that choosing each menu is independent of the other menu choices, or that modifying one menu has no impact on the profits generated by the other menus.

Then, for any menu $X_i$ part of an optimal mechanism, we need this menu to maximize $\Pi(X_i)$ among all possible menus of size up to $\overline{m}$. By Assumption 3, there is a unique menu that maximizes this expression. This implies that only such a menu could be part of an optimal mechanism. □

# 7 Concluding Remarks

In this paper we analyze the product line design problem of a monopolist interacting with consumers that remain unaware of the products he is offering. Consumers sample offers from the monopolist's menu at random, and decide whether to purchase one of the sampled alternatives if any. We find that if consumers cannot observe more than one sample from the menu, then the optimal menu for the monopolist include a single offer. This shows that when the distortions created by these informational frictions are severe, the monopolist will prefer to shut down any differentiation in his product line. When frictions are less severe and consumers can observe more than one offer, the optimal menu could take a less extreme structure and carry differentiated products. However, we show that it is never optimal for the monopolist to design a menu that contain only two offers in the same proportion: he always has an incentive to offer an unbalanced menu in which the most profitable offer appears more often.

The search frictions present in our framework makes the monopolist worse off compared to the case in which consumers observe the complete menu of offerings. As such, the monopolist has an incentive to increase consumers' awareness and knowledge of the product line if he has the opportunity to do so. However, if frictions persist or he cannot fully control the matching process, our results highlight that the monopolist not necessarily simplify his offerings and could obfuscate his product line in order to increase his expected profits.

We focus on the problem of a monopolist in our model. Competition among different sellers could indeed change the types of products each firm will offer in equilibrium. Another interesting path to pursue would be to explore how different types of competitive arrangements would impact the problem of the seller in this context.

Our model abstracts from any form of direct targeting: all consumers face the same menu and have the same probability of observing each alternative. Since the use of advertising tailored to specific types of consumers is well spread in today's economy, a natural extension of our model would consider the impact of partially personalized menus into the design problem of the firm.

Finally, while we focus on the arrangement of products that a firm will decide to offer in a consumption market, we think our model could be applied to more general settings in which the decisions of the agents are based on imperfect observation or evaluation of the set of alternatives designed by a principal. For example, our framework could be modified to be used to analyze a problem in which agents are interacting with a complex tax benefits system. Here, agents will be unable to consider all benefits they are eligible for and instead randomly receive "offers" with some of those benefits to apply for. In the light of our results, an uniform policy could be preferable when frictions are severe, and the use of differentiated policies can only be justified if frictions are less severe. We think our model provide a simple framework to analyze how benefits should be designed and prioritize if agents fail to consider them all at once.

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