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Investment in product experimentation when consumers are loss averse

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Abstract

I investigate the equilibrium outcomes of a game in which a monopolist sells to loss averse consumers, who are uncertain about their tastes for the product on sale. To resolve valuation uncertainty, the monopolist can invest in product experimentation, to improve the customers' purchasing decision. I characterize the optimal monopolist's price and investment in product experimentation. The analysis suggests that, to maximize social welfare, public authorities should force the firm to allow product experimentation for intermediate degrees of consumer loss aversion.

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1 Introduction

A recent report published by McKinsey (2014) shows that automotive original equipment manufacturers (OEM) are investing in advanced technology such as virtual showrooms and mobile sales assistants in order to improve the customer's purchase experience. This trend is common to many other sectors characterized by experience goods, such as the technology industry, which includes products like software, smartphones and video-games.

Allowing pre-purchase trials and providing demonstrations of the products on sale are marketing practices that have been recently studied in the IO literature. In particular, they have captured the attention of behavioral economists (e.g., Heidhues and Kőszegi, 2008, and Kőszegi and Rabin, 2006, 2007) who study strategic interactions between firms and loss averse consumers — i.e., individuals who are more sensitive to losses than equal-sized gains. In this case, product experimentation is usually seen favorably because it resolves uncertainty about the quality of the goods on sale. However, allowing test before purchase is usually costly for firms. Arranging tests for customers entails some costs related to the dedicated staff, the space for experimentations, the insurance premium etc. If these costs are sizeable, firms have less incentive to allow product experimentation. Moreover, testing products before purchase is not always effective in revealing the consumers' match value. This generally depends on the investment in product experimentation made by the firms. Obviously, the higher the experimentation effectiveness, the higher the benefit for customers.

In this paper, I investigate these issues in a monopoly framework, where consumers are loss averse. The concept of loss aversion, firstly applied to marketing issues by Kőszegi and Rabin (2006, 2007), has been recently studied in relation to firms disclosure policies by Karle and Schumacher (2016). In contrast to their model, in my paper the monopolist is uncertain about the quality perceived by the consumers. In fact, consumers' tastes and their match values are unknown to the firm because they are often the result of a subjective assessment (see Hahn, 2005). Moreover, allowing product experimentation is costly and its effectiveness is driven by the monopolist's investment choice. Piccolo and Pignataro (2018), instead, show the effect of allowing product experimentation in a duopoly on the profitability and sustainability of tacit collusion. However, in their model, product experimentation resolves valuation uncertainty completely, while in this paper it may help consumers in making their purchase decision with some probability. Furthermore, testing products is much more valuable for consumers under a monopoly rather than in a duopoly, where it makes products differentiated and lets firms charge above their marginal costs. These differences dramatically change the equilibrium outcomes and the policy implications.

I characterize the optimal monopolist price and disclosure policy. The results show some interesting comparative statics. Specifically, customers are not allowed to test the product on sale for small degrees of loss aversion. Instead, the investment in product experimentation becomes positive (and maximum) when consumers are sufficiently loss averse. Since testing the product does not avoid the possibility to get losses with respect to the consumers' expectations (which are unknown to the monopolist), the investment is decreasing in the degree of loss aversion.

The analysis pins down a region of parameters in which consumers would be willing to pay a higher price in order to test the product before purchase, whereas the monopolist prefers to avoid testing. Since product experimentation is a vital source of information for customers (see McKinsey report, 2014), it must be allowed when it is feasible for the monopolist and optimal from a social welfare point of view. The analysis suggests an effective policy intervention aiming at forcing the firm to invest in product experimentation for intermediate degrees of consumer loss aversion.

2 The Model

A monopolist produces a good at constant marginal cost $c \geq 0$ and sells it to a unit mass of consumers. Each consumer purchases at most one unit of product. Firm and consumers are both uncertain about how well the product fits with the consumers' tastes: they only know that consuming the good on sale yields a utility θ with $\theta \sim U[0,1]$.

Following Heidhues and Kőszegi (2008), I assume that consumers are loss averse, while the monopolist is loss-neutral. Specifically, consumers have the following utility function

$$u(\theta, p, r) \triangleq \theta - p + \mu(\theta, p, r), \tag{1}$$

which is a simplified version of reference-dependent preferences introduced by Kőszegi and Rabin (2006, 2007).[1] The variable p is the price charged by the monopolist, $\mu(\theta, p, r)$ is the following gain–loss function[2]

$$\mu(\theta, p, r) \triangleq \begin{cases} \theta - p - r & \text{if } \theta - p \geq r \\ \alpha(\theta - p - r) & \text{if } \theta - p < r \end{cases} \tag{2}$$

and $\alpha \geq 1$ represents the degree of consumer loss aversion.[3] The parameter r is the consumers'

[1]The gain-loss utility is defined over the net utility associated with buying the product at a certain price, while Kőszegi and Rabin (2006, 2007) assume that the gain-loss utility is computed separately for the consumption value and the price.

[2]See Kahneman and Tversky (1979) for a detailed description of the value function.

[3]The parameter α can be also interpreted as a sort of degree of risk-aversion. However, the presence of a (stochastic) reference point makes the model typical of that one characterizing a purchase decision of loss averse consumers.

reference point — i.e., their expectation about the net valuation for the product on sale, given the price posted by the monopolist. Consumers feel a psychological gain or loss for every outcome above or below r, which is assumed to be stochastic and unknown to the monopolist. For simplicity, the reference point has the same distribution of θ, but they are considered as two independent random variables. Since, it incorporates the price set by the monopolist, it is distributed over the continuous set $[-p, 1-p]$.[4] Hence, the utility function if experimentation is not allowed is

$$u^N(p) \triangleq \int_{-p}^{1-p} \left(\int_0^{p+r} (\theta - p + \alpha(\theta - p - r))\, d\theta + \int_{p+r}^{1} (\theta - p + (\theta - p - r))\, d\theta \right) dr. \tag{3}$$

The external integral in (3) represents the variation of the reference point. Instead, the internal integrals represent the consumer utility in case of an expected loss and gain respectively. Consumers learn θ only after consumption. Therefore, if product experimentation is not allowed, their willingness to pay is given by the comparison between the expected utilities with gains and losses (with respect to the reference point).

However, the monopolist can allow consumers to test its product before purchase, at a convex cost $I(q) = \frac{k}{2}q^2$, where $k > 0$ and $q \in [0, 1]$ represents the effectiveness of product experimentation.[5] In fact, testing the product resolves completely uncertainty with probability q, while it does not affect the *ex ante* valuation with probability $1 - q$. Hence, if consumers decide to test the product, the expected utility is

$$u^T(p, q) \triangleq \underbrace{q \left(\int_{-p}^{1-p} \int_0^1 \max\{0, u(\theta, p, r)\}\, d\theta dr \right)}_{\text{Informative test}} + \underbrace{(1-q) \max\left\{0, u^N(p)\right\}}_{\text{Uninformative test}}. \tag{4}$$

When product experimentation is informative in revealing the match value θ, consumers purchase the product if and only if the utility is larger than the outside option, which is normalized to zero without loss of generality. Otherwise, they prefer not to buy the good on sale. As a tie-breaking condition, when consumers are indifferent between testing or not, or purchasing or

[4] There exists a large debate on what the reference point is and how to evaluate it. For instance, Tversky and Kahneman (1979) have defined it as the *status quo* of consumers. Instead, Kőszegi and Rabin (2006, 2007) have recently argued that it is formed by (behavioral biased) consumers' rational expectations. In this model, to avoid any assumption on it and to get results as general as possible, I impose that the monopolist does not know the consumers' reference point and has no information about how it is formed. This approach seems to be more realistic with respect to the standard literature, because it does not entail any degree of consumers' rationality (see e.g., Baillon *et al.*, 2016, and Sprenger, 2015, for experimental evidences).

[5] Setting q allows the monopolist to establish the effectiveness of product experimentation. Indeed, companies like Porsche and Land Rover invest in facilities properly aiming at reducing the randomness of consumers' pre-purchase experience (see Ert *et al.*, 2016).

not the product, they choose the former option. Instead, when testing product before purchase is uninformative, consumers have two alternative options: (i) not buying the product; (ii) purchasing it without knowing the actual value of θ.

The timing is as follows:

- The monopolist produces the good, posts p and decides how much to invest in product experimentation by setting q.[6]
- Each consumer observes the monopolist's offer and decides whether to test the product.
- If experimentation is performed, uncertainty resolves with probability q.
- Each consumer makes his purchase decision.

Since the monopolist does not know the match value θ, there is no way to signal the quality of the product through prices or disclosure policies.[7] *Behind this veil of ignorance*, the monopolist sets p and q in order to maximize its expected profit, while consumers make the purchase decisions that maximize the expected utility, given their reference point. Hence, the solution concept I employ is Subgame Perfect Nash Equilibrium (SPNE).

3 Equilibrium Analysis

3.1 If test is not allowed

Suppose that the monopolist does not allow consumers to test its product — i.e., $q = 0$. Since there is no competitive pressure in the market, it charges a price that fully extracts the consumer expected surplus — i.e., $u^N(p) = 0$ — which yields a price

$$p^N(\alpha) = \frac{4-\alpha}{6}.$$

Charging this price allows the monopolist to sell its product with probability 1. Since it does not incur any cost for tests, its profit coincides with the price minus the production cost — i.e., $\pi^N\left(p^N(\alpha), q=0\right) = \frac{4-\alpha}{6} - c$. Hence, the monopolist's necessary condition for producing the good and not allowing product experimentation is the following.

[6]Fixing $q = 0$ is equivalent not to allow product experimentation.

[7]See, for example, Rhodes and Wilson (2016) for an analysis on signaling problems in the monopoly case.

Lemma 1 *There exists a threshold* $\alpha^*(c) \geq 1$ *such that* $\pi^N\left(p^N(\alpha), q=0\right) \geq 0$ *if and only if* $\alpha \leq \alpha^*(c)$ *with* $c \in [0, \mathbb{E}[\theta]]$.

As intuition suggests, profit is decreasing in α. Indeed, a high degree of loss aversion implies a large price discount that the monopolist must offer in order to induce consumers to buy the product without knowing the match value θ. If the price discount is too high, the price does not cover the marginal cost and the monopolist prefers not to produce.

3.2 If test is allowed

Suppose now that the monopolist invests in product experimentation — i.e., $q > 0$. In equilibrium, consumers never purchase the product when the test is uninformative. In fact, since allowing product experimentation is costly, the monopolist charges a price $p^T > p^N$. This implies that, given the price p^T, the consumer utility falls short of the outside option whenever the test is uninformative. Hence, the monopolist profit function is

$$\pi^T\left(p^T, q\right) = q \times p^T \times \Pr\left[u^T \geq 0\right] - \frac{k}{2}q^2 - c, \tag{5}$$

with

$$\Pr\left[u^T \geq 0\right] = \int_0^{1-p^T}\left(1 - p - \frac{\alpha}{1+\alpha}r\right)dr + \int_{-p^T}^{0}\left(1 - p - \frac{1}{2}r\right)dr. \tag{6}$$

Maximizing with respect to p^T and q yields the following optimal bundle of price and investment in product experimentation

$$p^T(\alpha) = \frac{\sqrt{2\left(3\alpha^2 + 3\alpha + 2\right)} - 4}{3(\alpha - 1)},$$

$$q(\alpha, k) = \begin{cases} 1 & \text{if} \quad k < \underline{k}(\alpha) \\ \frac{\left(3\alpha\sqrt{2}(1+\alpha) - 2\sqrt{3\alpha+3\alpha^2+2} - 2\sqrt{2}\right)\left(\sqrt{3\alpha+3\alpha^2+2} - 2\sqrt{2}\right)}{27(\alpha-1)^2(\alpha+1)k} & \text{if} \quad k \geq \underline{k}(\alpha) \end{cases},$$

where $\underline{k}(\alpha)$ is a threshold that makes q not larger than one.[8] It is worth noting that q is (weakly) decreasing in k. Clearly, the monopolist fully reveals the match value θ when the investment is not too costly.

The comparative statics of $p^T(\alpha)$ and $q(\alpha, k)$ provide two interesting results. First, the price charged by the monopolist is increasing in α. The reason is that a high degree of loss aversion

[8] Note that the optimal price and investment are both between 0 and 1. The profit function is continuous in that interval and it has clearly its minimum in $p = 0$ and $q = 0$. Hence, for the Weierstrass theorem, $p^T(\alpha)$ and $q(\alpha, k)$ maximize the profit function.

means that consumers value more the possibility to test product before purchase, so increasing their willingness to pay. Second, the investment in product experimentation is decreasing in α. This counterintuitive result derives from the negative effect of α on the purchase probability (6): the more loss averse consumers are, the larger is the utility loss when their expectations are not met, so reducing the profitability of allowing product experimentation.

Substituting $p^T(\alpha)$ and $q(\alpha, k)$ into (5) yields the monopolist profit function $\pi^T(\alpha, c, k)$, which is decreasing in the parameters. The following lemma provides the necessary condition for producing the good and allowing product experimentation.

Lemma 2 *There exists a threshold $c^*(\alpha, k) \geq 0$, which is decreasing in α and k, such that $\pi^T\left(p^T(\alpha), q(\alpha, k) > 0\right) \geq 0$ if and only if $c \leq c^*(\alpha, k)$.*

From the consumers' perspective, product experimentation is always welfare increasing. Consumers have always incentive to test the product if it is allowed. Indeed, doing so, they avoid bad purchases. Moreover, substituting $p^T(\alpha)$ and $q(\alpha, k)$ into (4) yields the expected utility $u^T\left(p^T(\alpha), q(\alpha, k) > 0\right)$, which is strictly positive. It is also worth noting that product experimentation is beneficial to consumers, even though it implies a price $p^T(\alpha)$ larger than $p^N(\alpha)$. In fact, the benefit from knowing the match value θ exceeds the price hike.[9]

3.3 Equilibrium outcome

Building on the previous analysis, I characterize now the conditions under which product experimentation is an equilibrium outcome. Specifically, the monopolist has an incentive to allow product experimentation only if

$$\pi^T\left(p^T(\alpha), q(\alpha, k) > 0\right) \geq \pi^N\left(p^N(\alpha), q = 0\right). \tag{7}$$

It is easy to verify that there exists a threshold $\widehat{\alpha}(k)$ such that (7) is satisfied for $\alpha \geq \widehat{\alpha}(k)$.[10] This condition, together with the non-negative profit constraints, characterize the optimal monopolist offer. In the following proposition, I show the equilibrium outcomes and the region of parameters in which the monopolist exploits its dominant position and does not allow product experimentation.

[9] This is in sharp contrast with the existing literature when consumers are not loss averse (Hahn, 2005). By contrast, it echoes the results of Piccolo and Pignataro (2018) when the market is monopolized by two colluding firms.

[10] Note that $\widehat{\alpha}(k)$ is increasing in k: the higher the cost for allowing experimentation, the larger must be the degree of consumer loss aversion to induce the monopolist to invest in product experimentation.

Proposition 1 *For $c \in [0, \mathbb{E}[\theta]]$ and $\alpha < \min\{\widehat{\alpha}(k), \alpha^*(c)\}$ there exists a unique SPNE in which product experimentation is not allowed — i.e., $q = 0$ — and the monopolist charges $p = p^N(\alpha)$. By contrast, for $c \leq c^*(\alpha, k)$ and $\alpha \geq \widehat{\alpha}(k)$, the game features a unique SPNE in which the monopolist offers $q(\alpha, k) > 0$ and $p^T(\alpha)$. In any other case, production does not occur.*

Production occurs only if production costs are low enough. However, this could not be sufficient if consumers are very loss averse and the investment in product experimentation is too costly.

Proposition 1 shows also that not allowing test before purchase is a profitable marketing strategy only if it does not require a too large price discount. Although the monopolist participation constraint is satisfied for any $q \in [0, 1]$, the investment in product experimentation is zero for small degrees of consumer loss aversion — i.e., $\alpha < \widehat{\alpha}(k)$ —, while it is strictly positive and decreasing in α for $\alpha \geq \widehat{\alpha}(k)$. There is therefore a point of discontinuity in $q(\widehat{\alpha}(k), k)$, where $q(\widehat{\alpha}(k), k)$ is maximum. Indeed, when consumers are not too loss averse, product experimentation is not so valuable for them. Conversely, for sufficiently large degrees of loss aversion, consumers are willing to pay more in order to test the product. However, an increase in α decreases the probability of selling the product, then the investment profitability. The reason is that product experimentation does not avoid losses completely with respect to consumers' expectations. The figure below provides an exemplificative graphical illustration for $k > \underline{k}(\alpha)$ and sufficiently small marginal costs (such that the participation constraint is satisfied).

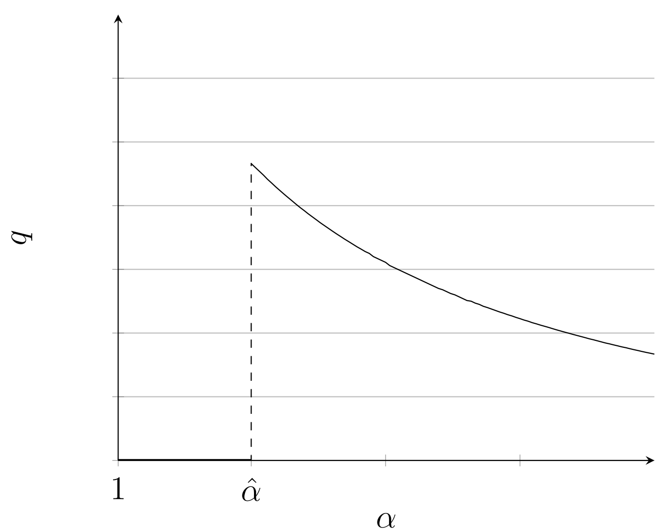

Figure 1: Investment in product experimentation

The monopolist does not allow consumers to test its product before purchase when the degree of loss aversion is sufficiently small. However, for $\alpha \geq \hat{\alpha}$, the investment in product experimentation becomes positive, smaller than one (because $k > \underline{k}(\alpha)$) and decreasing in the degree of loss aversion.

Product experimentation is beneficial to consumers, but it does not necessarily guarantee the monopolist to reach the break-even point. Hence, if a public Authority aims at maximizing the consumer surplus, it can force experimentation only if the monopolist is guaranteed non-negative profits — i.e, $c \leq c^* (\alpha, k)$. However, the main goal of Competition Authorities is often the maximization of total welfare — i.e., the sum of consumer and producer surplus.[11] In this case, product experimentation should be mandatory if and only if the consumers' benefit compensates the monopolist's loss, i.e.

$$u^T \left(p^T (\alpha), q(\alpha, k) > 0\right) \geq \pi^N \left(p^N (\alpha), q = 0\right) - \pi^T \left(p^T (\alpha), q(\alpha, k) > 0\right). \tag{8}$$

This suggests the following policy intervention.

Proposition 2 *Suppose that* $c \leq c^* (\alpha, k)$*, then for* $\alpha \leq \widehat{\alpha}(k)$ *consumer surplus is maximized by a policy that forces the monopolist to invest in product experimentation. There exists also a threshold* $\widetilde{\alpha}(k) \geq 1$ *such that total welfare is maximized for* $\alpha \in [\widetilde{\alpha}(k), \widehat{\alpha}(k)]$.

Proposition 2 provides a counterintuitive result, according to which forcing product experimentation is socially optimal for intermediate degrees of consumer loss aversion and sufficiently small monopolist's costs. The reason is the following. Allowing consumers to test the product before purchase must satisfy the monopolist's participation contraint. This implies that manufacturing the product and allowing experimentation must not be too costly. Moreover, to maximize total welfare the consumer utility gain must compensate the monopolist's loss. As stated above, the lower the degree of consumer loss aversion, the higher the monopolist profit when experimentations are not allowed. Hence, a policy intervention is effective only if consumers are not too loss averse.

4 Conclusions

Building on the recent literature on loss aversion, I have characterized the equilibrium outcomes of a game in which a monopolist can allow perspective customers to test a product before purchase. In this article, I have highlighted how the degree of consumer loss aversion drives the monopolist's marketing strategies. The analysis suggests that product experimentation is allowed when consumers are sufficiently loss averse. Yet, if test is allowed, this investment is decreasing in the degree of consumer loss aversion.

I have shown also that there exists a region of parameters in which the monopolist exploits its dominant position and does not allow product experimentation, although consumers would be

[11] See e.g., Motta (2004) for a description of the objectives of a Competition Authority.

willing to pay a higher price in order to test product before purchase. This happens when arranging experimentation is not too costly and consumers are not too loss averse. This result pinpoints an area for a policy intervention where the firm must be forced to allow product experimentation. Specifically, to maximize total welfare, a public Authority should make product experimentation mandatory by law for intermediate degrees of consumer loss aversion.

A Appendix

Proof of Lemma 1. Not allowing product experimentation is profitable only if $\pi^N\left(p^N(\alpha), q=0\right) \geq 0$, which implies $\frac{4-\alpha}{6} - c \geq 0$. Being $\alpha \geq 1$, this inequality is satisfied only for $c \in \left[0, \frac{1}{2}\right]$ and $\alpha \in [1, 4-6c]$. ■

Proof of Lemma 2. Allowing product experimentation is profitable only if $\pi^T(\alpha, c, k) \geq 0$, which is satisfied for $c \leq qp\frac{2\alpha+4(1-p)-p^2(\alpha-1)}{4(\alpha+1)} - \frac{k}{2}q^2$ and $q \in (0,1]$. Using the profit maximizing values $p^T(\alpha)$ and $q(\alpha, k) > 0$, by the Envelope Theorem it is easy to verify that $\frac{\partial \pi^T(\alpha,c,k)}{\partial k} < 0$ and $\frac{\partial \pi^T(\alpha,c,k)}{\partial \alpha} < 0$. This implies also that $c^*(\alpha, k)$ is decreasing in α and k. ■

Proof of Proposition 1. It is straightforward to show that production occurs if and only if the profit is non-negative, as stated in Lemma 1 and Lemma 2. In the following, I prove for which values of α allowing product experimentation is an equilibrium outcome, under the assumption that it yields non-negative profits. Suppose that $k \to 0^+$, then $q = 1$ and $p = p^T(\alpha)$ if test is allowed. This implies that $\pi^T\left(p^T(\alpha), q=1\right) = \frac{\sqrt{2}\sqrt{3\alpha+3\alpha^2+2}\left(\frac{2}{3}+\alpha(1+\alpha)\right)-\frac{1}{9}\sqrt{2}\left(3\alpha+3\alpha^2+2\right)^{\frac{3}{2}}-4\alpha(1+\alpha)+\frac{8}{9}}{6(\alpha+1)(\alpha-1)^2} - c$. Comparing $\pi^T\left(p^T(\alpha), q=1\right)$ with $\pi^N\left(p^N(\alpha), q=0\right) = \frac{4-\alpha}{6} - c$, it turns out that $\pi^T\left(p^T(\alpha), q=1\right) \geq \pi^N\left(p^N(\alpha), q=0\right)$ if and only if $\alpha \geq \widehat{\alpha}(k=0) \approx 2.34$. Since $\pi^T\left(p^T(\alpha), q(\alpha,k) > 0\right)$ is strictly decreasing in k, there exists, for any $k \geq 0$, a $\widehat{\alpha}(k)$ larger than $\widehat{\alpha}(k=0)$ such that $\pi^T\left(p^T(\alpha), q(\alpha,k) > 0\right) \geq \pi^N\left(p^N(\alpha), q=0\right)$. ■

Proof of Proposition 2. In the following, I prove that there can exist a $\widetilde{\alpha}(k) \in [1, \widehat{\alpha}(k)]$ such that $u^T\left(p^T(\alpha), q(\alpha,k) > 0\right) \geq \pi^N\left(p^N(\alpha), q=0\right) - \pi^T\left(p^T(\alpha), q(\alpha,k) > 0\right)$ for $\alpha \geq \widetilde{\alpha}(k)$. Suppose that $k \to 0^+$ and $\alpha = 1$, then $u^T\left(p^T(\alpha=1), q=1\right) \approx 0.16$, while $\pi^N\left(p^N(\alpha=1), q=0\right) - \pi^T\left(p^T(\alpha=1), q(\alpha=1, k=0) > 0\right) \approx 0.22$. Instead, for $\alpha \approx 2.34$, $u^T\left(p^T(\alpha=1), q=1\right) \approx 0.34$, while $\pi^N\left(p^N(\alpha=2.34), q=0\right) - \pi^T\left(p^T(\alpha=2.34), q(\alpha=2.34, k=0) > 0\right) = 0$. Since $\frac{\partial u^T\left(p^T(\alpha),q(\alpha,k)>0\right)}{\partial \alpha} > 0$ and $\frac{\partial^2 u^T\left(p^T(\alpha),q(\alpha,k)>0\right)}{\partial \alpha^2} > 0$, then $u^T\left(p^T(\alpha), q(\alpha,k) > 0\right)$ is an increasing and convex function in α. Instead, $\frac{\partial \pi^N\left(p^N(\alpha),q=0\right)}{\partial \alpha} < 0$ and $\frac{\partial \pi^T\left(p^T(\alpha),q(\alpha,k)>0\right)}{\partial \alpha} < 0$, then both profit functions are decreasing in α. Consider that $\frac{\partial^2 \pi^N\left(p^N(\alpha),q=0\right)}{\partial \alpha^2} = 0$, then $\pi^N\left(p^N(\alpha), q=0\right)$ is linearly decreasing in α, while $\frac{\partial^2 \pi^T\left(p^T(\alpha),q(\alpha,k)>0\right)}{\partial \alpha^2} > 0$, then $\pi^T\left(p^T(\alpha), q(\alpha,k) > 0\right)$ is convex in α. Hence, the difference in profits is strictly decreasing in α. Since the utility and profit functions are both continuous and monotonic for any $\alpha \geq 1$, there exists a unique $\widetilde{\alpha}(k) \in [1, \widehat{\alpha}(k)]$ such that $u^T\left(p^T(\alpha), q(\alpha,k) > 0\right) \geq \pi^N\left(p^N(\alpha), q=0\right) - \pi^T\left(p^T(\alpha), q(\alpha,k) > 0\right)$ for $\alpha \geq \widetilde{\alpha}(k)$. ■

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