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A Note on Consumer Flexibility, Data Quality and Collusion

Irina Hasnas*

April 2014

Abstract

In this note we analyze the sustainability of collusion in a game of repeated interaction where firms can price discriminate among consumers based on two types of customer data. This work is related to Liu and Serfes (2007) and Sapi and Suleymanova (2013). Following Sapi and Suleymanova we assume that consumers are differentiated both with respect to their addresses and transportation cost parameters (flexibility). While firms have perfect data on consumer addresses, data on their flexibility is imperfect. We use three collusive schemes to analyze the impact of the improvement in the quality of customer flexibility data on the incentives to collude. In contrast to Liu and Serfes in our model it is the customer flexibility data which is imperfect and not the data on consumer addresses. However, our results support their findings that with the improvement in data quality it is more difficult to sustain collusion.

JEL-Classification: D43; L13; L15; O30.

Keywords: Price Discrimination, Customer Data, Collusion.

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1 Introduction

Advances in information technologies allow firms to collect, store and analyze various types of customer data including demographics (address, gender, age, income) and data on previous purchases.[1] This data may give insights into consumers' preferences and flexibility, allowing firms to price discriminate among them. Ever since Thisse and Vives (1988) it is known that competitive price discrimination may intensify competition and decrease firms' profits, as a result firms could collude not to acquire customer data and/or share the market.[2,3]

In this note we analyze how incentives to collude depend on the quality of customer data. Following Sapi and Suleymanova (2013) we introduce two-dimensional consumer heterogeneity and assume that consumers are heterogeneous both with respect to the brand preferences and the strength thereof. Respectively, two types of customer data are available to firms. Furthermore, we assume that data on consumer address is perfect and data on their flexibility is not. For example, in location-based marketing firms know the precise location of each consumer, while consumer sensitivity to different marketing activities (like price reductions and advertising) can be estimated only with less-than-perfect accuracy.[4] We follow Liu and Serfes (2007) to model imperfect customer data. We assume that firms are able to correctly identify different flexibility segments and can allocate any consumer to one of the segments.[5] When the quality of customer flexibility data improves, consumer segmentation becomes finer.

The articles most closely related to this paper are Liu and Serfes (2007) and Sapi and Su-

[1] For example, IBM provides data processing platforms and Business analytics software which help firms to store, process, forecast and statistically analyze various data (http://www-01.ibm.com/software/data/bigdata/platform/product.html).

[2] In telecommunications market, firms collect large amounts of customer data such as name, gender, physical address and calling history. In 2005 Conseil de la Concurrence fined three biggest French mobile operators for engaging in anticompetitive agreements. These companies were accused of sharing customer data and sharing the market. http://www.autoritedelaconcurrence.fr/user/standard.php?id_rub=160&id_article=502

[3] In the airline industry firms collect customer data through Frequent Flyer Program (FFP) and use it for third degree price discrimination. Customers can opt in and receive discounts based on the total amount of miles they fly. In 1999 two Scandinavian airlines SAS and Maersk Air notified the European Commission about a cooperative agreement that included code-sharing on a number of routes and FFP extension that allowed Maersk customers to earn points when flying with SAS and *vice versa*. However, in 2001 the European Commission fined the airlines for market-sharing agreement. (Sun-Air versus SAS and Maersk Air, 2001)

[4] Epling (2002) uses data from long-distance telephony to show that information on customer's location and income allows firms to better price-discriminate among consumers.

[5] Angwin (2010) describes how various internet companies collect personal information (location, age, gender, income, education, marital status, etc.) about websites' users and sell it to marketers and advertisers. The data can be of any quality: "We can segment it all the way down to one person" says Eric Porres, Lotame's chief executive officer.

leymanova (2013). Liu and Serfes analyze firms' incentives to collude depending on the quality of the data on consumer brand preferences when consumers are differentiated only along that dimension. Sapi and Suleymanova analyze firms' incentives to acquire imperfect customer flexibility data when data on consumer addresses is perfect and both firms hold it. In their analysis consumers are differentiated along two dimensions: brand preferences and the strength thereof. Following Sapi and Suleymanova (2013) we introduce consumer heterogeneity in transportation cost parameters and analyze firms' incentives to collude depending on the quality of data on consumer flexibility.

This note is organized as follows. Section 2 presents the model. In Section 3 we provide the equilibrium analysis and analyze firms' incentives to collude. We consider three collusive schemes: In the first scheme firms collude both in prices and their data acquisition decisions; in the second, they collude only in prices; in the third, they compete in prices and collude in data acquisition decisions. Section 4 compares the three schemes. We conclude in Section 5.

2 The Model

There are two firms, A and B, each situated at the end of a unit interval. Firm A is located at $x_A = 0$, and Firm B at $x_B = 1$. Each firm produces a brand of the same good. We normalize the marginal cost of production of such good to zero. There is a mass of consumers normalized to unity. We follow Sapi and Suleymanova (2013) and assume that consumers are differentiated both with respect to their address and transportation cost parameters. Therefore, every consumer is uniquely described by a pair of parameters (x, t), where $x \in [0; 1]$ represents consumer's address and $t \in [\underline{t}; \overline{t}]$ is her flexibility, where $\underline{t} \geq 0$ and $\overline{t} > \underline{t}$. We assume that x and t are uniformly and independently distributed,; i.e., $f_t = 1/(\overline{t} - \underline{t})$, $f_x = 1$ and $f_{t,x} = 1/(\overline{t} - \underline{t})$.

We assume that both firms hold perfect information on consumer location. Firms can also acquire customer flexibility (transportation costs) data at zero cost. Data on consumer transportation costs is imperfect and characterized by the exogenously given quality parameter $k = 0, 1, 2, ..., \infty$. For any k firms are able to divide the interval $[\underline{t}; \overline{t}]$ into $n := 2^k$ segments and allocate each consumer to one of them. Every segment $m = 1, 2, ..., 2^k$ characterized by the transportation cost parameter $t^m \in [\underline{t}^m; \overline{t}^m]$, where $\underline{t}^m = \underline{t} + (\overline{t} - \underline{t})(m-1)/n$ and $\overline{t}^m = \underline{t} + (\overline{t} - \underline{t})m/n$. Higher k implies customer data of a finer segmentation of the interval $[\underline{t}; \overline{t}]$ and, hence, better data quality. If $k \to \infty$, firms have perfect information on consumers' transportation cost.

We follow Sapi and Suleymanova (2013) and consider two versions of the model, depending on consumer heterogeneity in flexibility measured by the ratio $l(\underline{t}, \overline{t}) := \overline{t}/\underline{t}$. In the first version consumers are *relatively heterogeneous* and $\underline{t} = 0$, such that $\lim_{\underline{t}\to 0} l(\underline{t}, \overline{t}) = \infty$. In the second version consumers are *relatively homogeneous,* such that $\underline{t} > 0$ and $l(\underline{t}, \overline{t}) \leq 2$.

If a firm acquires flexibility data, it charges different prices depending on a consumer's address, flexibility segment and the quality of customer data: $p_i(x, m; n)$ with $i \in \{A; B\}$. Therefore, two consumers at the same location that belong to different flexibility segments can be charged different prices. The utility of a consumer (x, t) in case of buying from Firm i is

$$U_i(p_i(x, m; n), t, x) = V - t|x - x_i| - p_i(x, m; n),$$

where $V > 0$ is the basic valuation of a product. In order to ensure that the market is always covered in equilibrium, we assume that V is large enough. A consumer always buys from a firm offering the highest utility. The indifferent consumer buys from the nearest firm.

We consider an infinitely repeated game. In a stage game firms decide simultaneously and independently whether to acquire customer flexibility data and which prices to charge. These decisions become a common knowledge at the end of each stage game and firms have a perfect memory of all past actions.

Firms may collude using trigger strategies, such that in period t a firm plays cooperatively if in period $t-1$ the rival played cooperatively. In other words, firms stick to the collusion agreement as long as nobody has deviated. However, if deviation takes place in period t, firms will play Nash Equilibrium from period $t+1$ to infinity. We denote the one-shot collusive profit of Firm i by $\pi_i^C(n)$, the deviation profit by $\pi_i^D(n)$, and non-cooperative profit by $\pi_i^N(n)$. Collusion can only be sustained in the infinitely repeated game if the discount factor is sufficiently high:

$$\delta \geq \overline{\delta}(n) \equiv \frac{\pi_i^D(n) - \pi_i^C(n)}{\pi_i^D(n) - \pi_i^N(n)},\ i \in \{A; B\}.$$

3 Equilibrium Analysis

Non-cooperative profits. Note that in our model firms make data acquisition decisions simultaneously with their price choices in a stage game, and therefore, in the non-cooperative equilibrium firms always acquire customer data. This is different from Sapi and Suleymanova

(2013), where these two decisions are made sequentially. Hence, the equilibrium prices in our analysis are same as in Sapi and Suleymanova in the subgame where both firms acquire customer data. The interval $[0; 1/2)$ represents *Firm A's turf* and the interval $(1/2; 1]$ is *Firm B's turf.* Given prices $p_A(x, m; n)$ and $p_B(x, m; n)$, the transportation cost parameter of the indifferent consumer on the segment m with address x is

$$\widetilde{t}(x, m; n) = \frac{p_A(x, m; n) - p_B(x, m; n)}{1 - 2x}, \text{ where } \widetilde{t}(x, m; n) \in [\underline{t}^m; \overline{t}^m].$$

On any segment m, Firm A serves its most loyal consumers with high transportation cost parameters $t \geq \widetilde{t}(x, m; n)$, and Firm B serves the least loyal consumers of Firm A with low transportation cost parameter, $t < \widetilde{t}(x, m; n)$. For any address $x \in [0; 1/2)$ and on any segment m, Firm A maximizes the expected profit

$$E[\pi_A(x, m; n)|x < 1/2] = p_A(x, m; n) \Pr\{t \geq \widetilde{t}(x, m; n)\},$$

while Firm B maximizes the expected profit

$$E[\pi_B(x, m; n)|x < 1/2] = p_B(x, m; n) \Pr\{t < \widetilde{t}(x, m; n)\}.$$

In our version of the model, the equilibrium prices and profits in the non-cooperative case are identical to those stated in Proposition 1 in Sapi and Suleymanova (2013) and depend on data quality and consumer heterogeneity in flexibility.

Proposition 1.(From Sapi and Suleymanova, 2013)

i) Assume that consumers are relatively differentiated. In equilibrium on Firm i's turf on the segment $m = 1$, *firms charge prices* $p_i^*(x, 1; n) = 2\overline{t}\,|1 - 2x|\,/(3n)$ *and* $p_j^*(x, 1; n) = \overline{t}\,|1 - 2x|\,/(3n)$. *Firm i serves consumers with* $t \geq \overline{t}/\,(3n)$. *On the segments* $2 \leq m \leq n$ *equilibrium prices are* $p_i^*(x, m; n) = \overline{t}\,(m - 1)\,|1 - 2x|\,/n$ *and* $p_j^*(x, m; n) = 0$, *where Firm i serves all consumers. Equilibrium profits are* $\Pi_i^*(n) = 5\overline{t}/(36n^2) + \overline{t}/8\,(1 - 1/n)$.

ii) Assume that consumers are relatively homogeneous. In equilibrium on Firm i's turf firms charge prices $p_i^*(x, m; n) = \left[\underline{t} + \left(\overline{t} - \underline{t}\right)(m - 1)\,/n\right]|1 - 2x|$ *and* $p_j^*(x, m; n) = 0$. *Firm i serves all consumers on its turf. Firms realize profits* $\Pi_i^*(n) = \underline{t}/4 + (\overline{t} - \underline{t})/8\,[1 - 1/n]$.

The following two graphs show how firms' non-cooperative profits change with the improve-

ment in the quality of customer flexibility data. We use the values $\underline{t} = 1$ and $\bar{t} = 2$ for the cases of relatively homogeneous and relatively differentiated consumers, respectively.

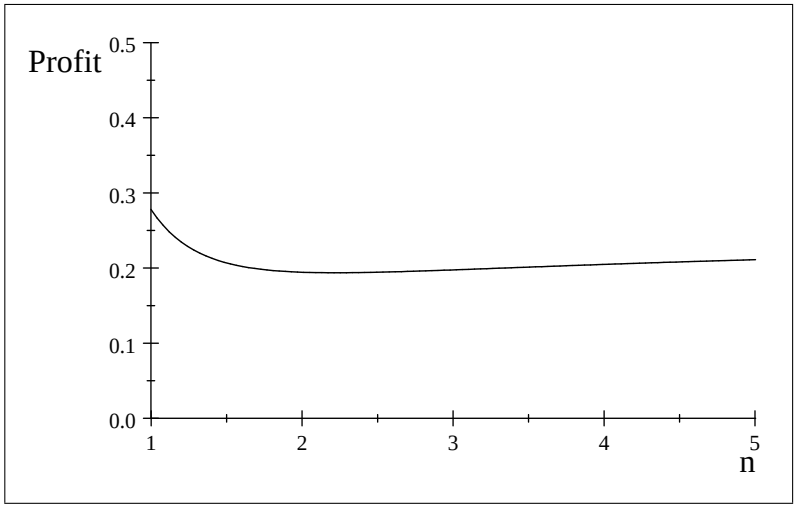

Figure 1. Non-cooperative profit with relatively differentiated consumers

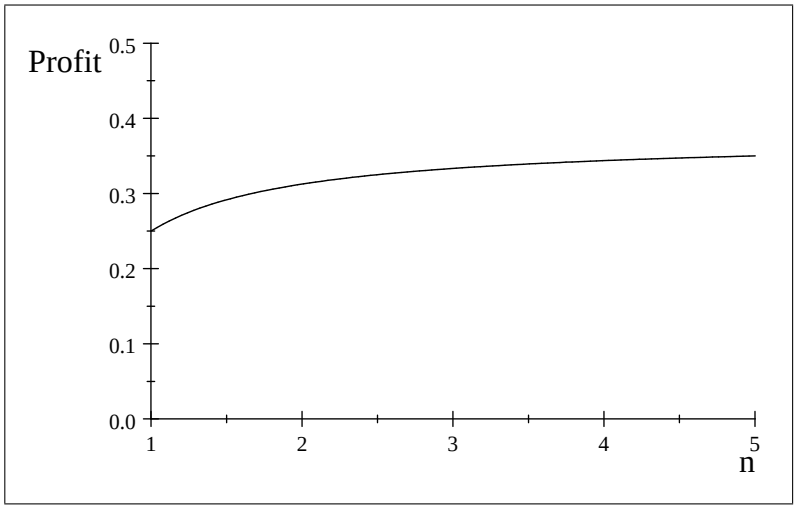

Figure 2. Non-cooperative profit with relatively homogeneous consumers

The two versions of the model (with relatively homogeneous and differentiated consumers) yield two different equilibria which are driven by the type of the best-response function of a firm on its turf. Precisely, as is shown in Sapi and Suleymanova (2013) when consumers are heterogeneous (homogeneous) a firm follows a *market-sharing* (*monopolization strategy*) on its turf in the absence of data on consumer flexibility. In the former case a firm optimally serves all consumers on its turf only if the rival's price is sufficiently high. Otherwise, a firm shares consumers on its turf with the rival. The reason is that it is costly for a firm to serve all consumers on its turf, because the most flexible consumer can switch brands costlessly. In equilibrium the

rival charges indeed a relatively low price and targets the least loyal consumers of a firm some of whom switch. As a result, in equilibrium firms serve consumers on both turfs. The acquisition of data of quality $k = 1$ intensifies competition as on both new segments the rival charges lower prices. As a result, profits decrease. However, with a further improvement in data quality profits start to increase since a firm can better target consumers, and the rent-extraction effect dominates.

When consumers are relatively homogeneous, for any price of the rival it suffice for a firm to decrease a little the price targeted at the least flexible consumers to attract all consumers with a given address. This makes it optimal for a firm to follow a monopolization strategy on its turf, such that for any price of the rival a firm optimally serves all consumers on its turf. Then in equilibrium the rival charges the price of zero on a firm's turf and competition is very intense. As the rival cannot decrease its price below zero, the acquisition of additional data gives rise only to the rent-extraction effect, and a firm's profits monotonically increase in data quality. In the case of relatively differentiated consumers the behavior of non-cooperative profits depending on data quality is similar to the one in Liu and Serfes (2007), because in both cases there is a consumer who can switch brands costlessly. This is the consumer with $x = 1/2$ in Liu and Serfes (2007) and the consumer with $t = 0$ in our case.

Collusive profits. Firms may collude along two dimensions: customer data acquisition decisions and pricing decisions. We follow Liu and Serfes (2007) and consider three collusive schemes. In the first scheme firms acquire customer flexibility data and charge monopoly discriminatory prices. Each firm acts as a monopolist on its own turf. Provided the basic valuation is high enough, all consumers are served under collusion, and every consumer buys from her most preferred firm at a price, which makes her indifferent between buying at that firm and not buying. This type of collusion leads to both firms using monopolization strategies regardless of consumers' heterogeneity in flexibility. If a firm deviates, it gains all consumers on the rival's turf. The following proposition states the collusive and deviation prices and profits for the first scheme.

Proposition 2. *Consider the collusive scheme under which firms acquire customer flexibility data and charge collusive prices. Assume that the basic utility is relatively large:* $V > \max\left\{\underline{t}/2 + (\bar{t} - \underline{t})(m+1)/(2n), \underline{t} + \frac{m+1}{n}(\bar{t} - \underline{t})\right\}$ *for any* m, n.

i) Under collusion, on its own turf on the segment m *and address* x, *Firm* $i = \{A, B\}$ *charges the*

price $p_i^C(x,m;n) = V - \left(\underline{t} + (\bar{t}-\underline{t})m/n\right)|x - x_i|$ *and serves all consumers there. The collusive profit of Firm* i *is* $\pi_i^C(n) = V/2 - \underline{t}/8 - (\bar{t}-\underline{t})(1+n)/(16n)$.

ii) If Firm j *deviates on the turf of Firm* i*, it charges the price* $p_j^D(x,m;n) = V - \left(\underline{t} + (\bar{t}-\underline{t})m/n\right)|x_j - x|$ *and serves all consumers. The price on its own turf does not change. The deviation profit of Firm* j *is* $\pi_j^D(n) = V - \underline{t}/2 - (\bar{t}-\underline{t})(1+n)/(4n)$.

Proof. See Appendix.

We now turn to the second collusive scheme. Under this scheme, firms collude by deciding not to acquire data on consumer flexibility and charge monopoly prices independently of consumer's flexibility. The following proposition states the collusive and deviation prices and profits for the second scheme.

Proposition 3. *Consider the collusive scheme under which firms do not acquire customer flexibility data and collude in prices. Assume that the basic utility is relatively large:* $V > \max\left\{\bar{t} - \underline{t}/2, \underline{t} + (m+1)/n(\bar{t}-\underline{t})\right\}$ *for any* m *and* n.

i) Under collusion, Firm $i = \{A, B\}$ *charges the price* $p_i^C(x) = V - \bar{t}\,|x - x_i|$ *to consumers with address* x*. The collusive profit of Firm* i *is* $\pi_i^C = V/2 - \bar{t}/8$.

ii) If Firm i *deviates, it acquires consumer flexibility data. On its own turf it charges the price* $p_i^D(x,m;n) = V - \left(\underline{t} + (\bar{t}-\underline{t})m/n\right)|x - x_i|$, and $p_i^D(x,m;n) = V - \bar{t}x - \left(\underline{t} + (\bar{t}-\underline{t})m/n\right)|2x - x_i|$ *on the rival's turf. The deviation profit of Firm* i *is* $\pi_i^D(n) = V - (\bar{t}+3\underline{t})/8 - 3(\bar{t}-\underline{t})(1+n)/(16n)$.

Proof. See Appendix.

When a firm deviates under the second collusive scheme, it acquires data on consumer flexibility and discriminates consumers with respect to their address and flexibility on both turfs. If the basic consumer valuation is high enough, then firms charge prices under which all consumers buy both under collusion and deviation. Firms use monopolization strategies. This implies that under collusion each firm serves all consumers on its own turf and none of the firms wants to target the most flexible consumers of the rival. However, if a firm deviates, then it serves all consumers on both turfs.

The results from Propositions 2 and 3 do not depend on consumers' heterogeneity. Under these collusive schemes, both firms optimally share and monopolize the market. They extract the highest possible rent from consumers and set such collusive prices that every consumer buys from its nearest firm. Under deviation, a firm undercuts the rival's collusive price and serves all consumers.

Finally, we consider the third collusive scheme, where firms agree not to acquire customer flexibility data and set competitive prices. This scheme does not make sense with relatively homogeneous consumers as for any quality of customer flexibility data it yields profits which are (weakly) smaller than the non-cooperative profits.[6] The reason being that in the non-cooperative equilibrium firms discriminate consumers based on their address and flexibility. Since the data on consumer address is perfect, the non-cooperative profit depends on the quality of the customer flexibility data: Sapi and Suleymanova (2013) find that the non-cooperative profits increase monotonically in data quality when consumers are relatively homogeneous. When firms agree to not acquire customer flexibility data and compete in prices (collusive scheme three), they discriminate consumers based solely on their address. Therefore when consumers are relatively homogeneous, the profits in the third scheme correspond to the lowest non-cooperative profits, i.e. when the quality of data is zero.

Hence, we consider this scheme only for relatively differentiated consumers. The following proposition states collusive and deviation profits under the third scheme.

Proposition 4. *Consider the collusive scheme under which firms do not acquire customer flexibility data and compete in prices.*
i) Under collusion, on Firm i's turf firms charge prices $p_i^C(x) = 2\bar{t}\,|1-2x|/3$ *and* $p_j^C(x) = \bar{t}\,|1-2x|/3$, *where* $i = \{A;B\}$ and $i \neq j$. *Firm i serves consumers with* $t \geq \bar{t}/3$. *Collusive profits are* $\pi_i^C = 5\bar{t}/36$.
ii) If Firm i deviates, it acquires customer flexibility data. Assume that $n > 2$ *(*$k > 1$*). On its own turf Firm i charges the deviation price* $p_i^D(x,m;n) = \bar{t}/3(3(m-1)/n+1)\,|1-2x|$. *On the rival's turf it charges the price* $p_i^D(x,m;n) = \bar{t}/3(2-3m/n)\,|1-2x|$ *to all consumers if* $m < 2n/3-1$, *and* $p_i^D(x,m;n) = \bar{t}/6(2-3(m-1)/n)\,|1-2x|$ *to consumers with flexibility* $t \in [\underline{t}^m; \bar{t}/3 + \underline{t}^m/2]$ *if* $m > 2n/3-1$. *The deviation profit of Firm i is*

$$\pi_i^D(n) = \frac{(5n-3)\bar{t}}{24n} + \sum_{m=1}^{[\frac{2n}{3}-1]} \int_{\frac{x_i}{2}}^{\frac{1}{2}(1+x_i)} \int_{\underline{t}^m}^{\bar{t}^m} f_t \frac{\bar{t}}{3}(2-\frac{3m}{n})\,|1-2x|\,dtdx$$

$$+ \sum_{m=[\frac{2n}{3}]}^{n} \int_{\frac{x_i}{2}}^{\frac{1}{2}(1+x_i)} \int_{\underline{t}^m}^{\bar{t}(\frac{1}{3}+\frac{m-1}{2n})} f_t \frac{\bar{t}}{6}(2-3\frac{m-1}{n})\,|1-2x|\,dtdx$$

Assume now that $n = 2$ *(*$k = 1$*). On its own turf Firm i charges the deviation price* $p_i^D(x,1;2) =$

[6] Under third scheme the collusive profit in case of relatively homogeneous consumers is $\pi_i^C = \frac{t}{4}$.

$(5\bar{t}/12)\,|1-2x|$ *if* $t \in [\bar{t}/12; \bar{t}/2]$, *and* $p_i^D(x,2;2) = (5\bar{t}/6)\,|1-2x|$ *if* $t \in [\bar{t}/2; \bar{t}]$. *On Firm* j*'s turf Firm* i *charges* $p_i^D(x,1;2) = (\bar{t}/3)\,|1-2x|$ *if* $t \in [0; \bar{t}/3]$, *and* $p_i^D(x,2;2) = (\bar{t}/12)\,|1-2x|$ *if* $t \in [\bar{t}/2; 7\bar{t}/12]$. *The deviation profit of Firm* i *is* $\pi_i^D = (17\bar{t})/96$.

Proof. See Appendix.

When firms collude under this scheme and consumers are relatively differentiated, every firm follows a market-sharing strategy on its turf and loses the less loyal consumers to the rival. The reason is that this type of collusion does not allow for price discrimination with respect to consumer flexibility, firms must set uniform prices to consumers with the same address. With relatively differentiated consumers, it is optimal for a firm to charge a relatively high price and target the most loyal consumers on its turf. As a result, under this collusive scheme each firm serves consumers on both turfs.

If a firm deviates, it acquires customer flexibility data of quality: $n \geq 2$.[7] When $n = 2$, it adopts a different deviation strategy than when $n > 2$. Let's consider the optimal deviation strategy on Firm i's own turf. If $n = 2$, Firm i follows a market-sharing strategy on the first segment and a monopolization strategy on the second. However, if $n > 2$, it follows a monopolization strategy on all segments. Now we turn to the optimal deviation strategy on a rival's turf. If $n = 2$, Firm i adopts a market-sharing strategy on both segments. However, if $n > 2$, it follows also a monopolization strategy on some segments according to the rule described in Proposition 4. These results are driven by the fact that consumers are relatively differentiated. When the deviation takes place on a firm's own turf, the negative competition effect is very strong when $n = 2$, and becomes weaker when n increases. When a firm deviates on the rival's turf, the competition effect there is even stronger, therefore, even with a data of better quality the deviating firm still targets only the most flexible consumers of the rival. Hence, when a firm deviates under the third scheme, it does not serve all consumers in the market.

[7] When $n = 1$, it stands for no data acquisition or customer data of zero quality, therefore we do not consider this case.

4 Comparison of the collusive schemes

Assumption 1. *Basic valuation is assumed to be sufficiently high, precisely* $V > 2\overline{t}$.[8]

To compare the three collusive schemes, we distinguish between two cases based on consumer heterogeneity. Consider first the case of relatively homogeneous consumers. Collusive scheme one can be sustained if the discount factor is relatively high:

$$\delta \geq \overline{\delta}_1(n) := \frac{\frac{V}{2} - \frac{3\underline{t}}{8} - \frac{(\overline{t}-\underline{t})}{16}(3+\frac{3}{n})}{V - \frac{3\overline{t}}{4} - \frac{\overline{t}-\underline{t}}{8}(3+\frac{1}{n})}.$$

The first order derivative of $\overline{\delta}_1(n)$ with respect to n is positive under Assumption 1. As $\overline{\delta}_1(n)$ is an increasing function of n, it implies that collusion becomes more difficult to sustain as the quality of customer flexibility data improves.

The second collusive scheme can be sustained if $\delta \geq \overline{\delta}_2(n)$, where

$$\overline{\delta}_2(n) := \frac{\frac{V}{2} - \frac{3\underline{t}}{8} - \frac{(\overline{t}-\underline{t})}{16}(3+\frac{3}{n})}{V - \frac{\overline{t}+5\underline{t}}{8} - (\overline{t}-\underline{t})(\frac{5n+1}{16n})}.$$

In Figure 3 we present $\overline{\delta}_2(n)$ as a function of $n = 1, ..., 2^k$.[9]

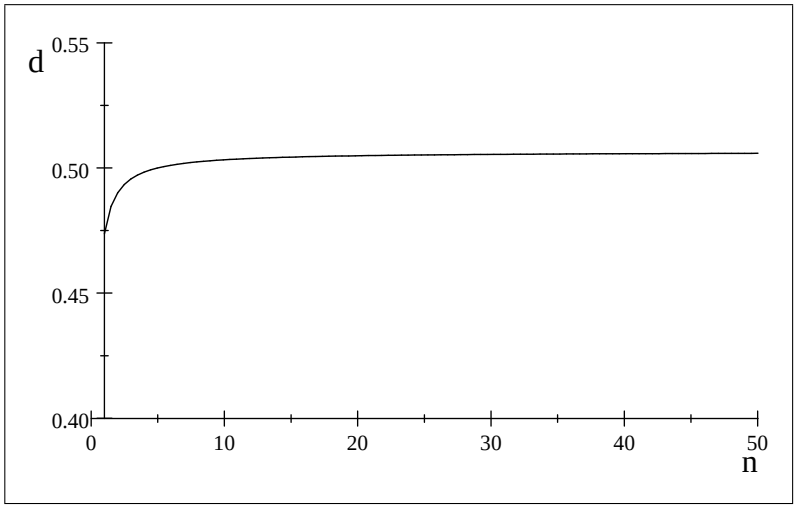

Figure 3. $\overline{\delta}_2(n)$ in case of relatively homogeneous consumers.

[8] Assumption 1 represents the strictest condition on V from Propositions 2 and 3 and it is obtained when $n = 1$ and $\underline{t} = 0$.

[9] In Figures 3 and 4 we use the following values: $V = 6$, $\overline{t} = 2$ and $\underline{t} = 1$ (in the case of relatively homogeneous consumers).

Again, the first-order derivative of $\overline{\delta}_2(n)$ with respect to n is positive. Similarly to the first collusive scheme, it becomes more difficult to sustain collusion when the quality of customer flexibility data improves. Moreover, it is easier to sustain the first collusive scheme: $\overline{\delta}_1(n) < \overline{\delta}_2(n)$ for any $n \geq 2$.[10] Liu and Serfes (2007) also get the latter result in a model where data on consumer addresses is imperfect.

We now turn to the case of relatively differentiated consumers, where

$$\overline{\delta}_1(n) := \frac{\frac{V}{2} - \frac{3\overline{t}(1+n)}{16n}}{V - \frac{5\overline{t}}{36n^2} - \frac{\overline{t}(3n+1)}{8n}}$$

$$\overline{\delta}_2(n) := \frac{\frac{V}{2} - \frac{3\overline{t}(1+n)}{16n}}{V - \frac{5\overline{t}}{36n^2} - \frac{\overline{t}}{8} - \frac{\overline{t}(5n+1)}{16n}}$$

First-order derivatives of $\overline{\delta}_1(n)$ and $\overline{\delta}_2(n)$ with respect to n are positive. In Figure 4 we present $\overline{\delta}_2(n)$ in case of relatively differentiated consumers.[11]

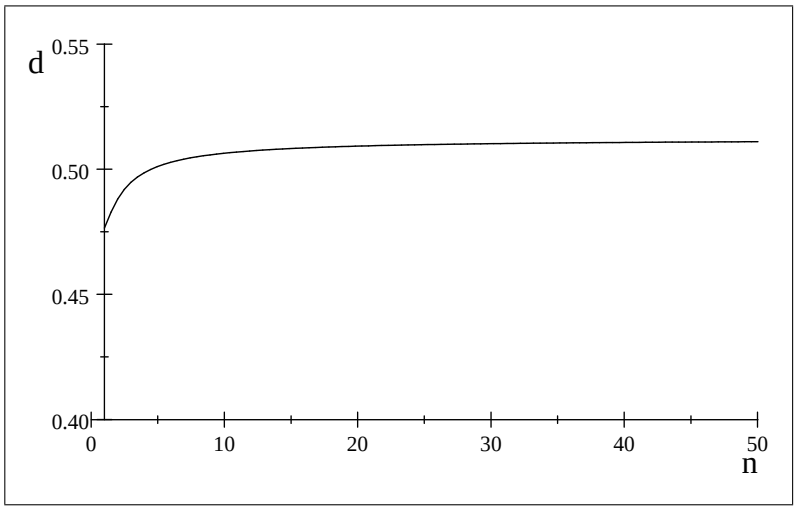

Figure 4. $\overline{\delta}_2(n)$ in case of relatively differentiated consumers.

In the third collusive scheme, $\overline{\delta}_3(n)$ cannot be derived analytically. We estimate $\overline{\delta}_3(n)$ for different values of the initial parameters in the model. Our results show that $\overline{\delta}_3(n)$ is an increasing function of n.[12]

Our results support the findings of Liu and Serfes (2007) that it becomes more difficult to sustain collusion when the quality of customer data improves. We conclude that the above

[10] If $n = 1$ then $\overline{\delta}_1(n) = \overline{\delta}_2(n)$.

[11] We do not show the graphics for $\overline{\delta}_1(n)$, because they are analogous to those already presented for $\overline{\delta}_2(n)$.

[12] For example, for $\overline{t} = 10$, we get $\overline{\delta}_3(2) = 0.477$; $\overline{\delta}_3(4) = 0.679$; $\overline{\delta}_3(8) = 0.790$; $\overline{\delta}_3(16) = 0.856$.

result holds not only when the quality of data on consumer addresses improves, but also when the quality of data on consumer flexibility improves and firms hold perfect data on consumer locations. This result holds both when consumers are relatively homogeneous and relatively differentiated in flexibility, although the behavior of non-cooperative profits is different in the two cases. The intuition for this result is the following: As non-cooperative profits increase with the improvement in data quality when consumers are relatively homogeneous, the punishment following deviation becomes less severe with better data quality, which makes deviation more attractive.

5 Conclusion

We analyze the sustainability of collusion in an infinitely repeated game depending on the quality of customer flexibility data. We follow Sapi and Suleymanova (2013) and assume that consumers are differentiated both with respect to their address and flexibility. Therefore, firms can price-discriminate among consumers using two types of customer data: consumer address and flexibility. We assume that data on consumer address is perfect, while data on consumer flexibility is not. In this way we depart from Liu and Serfes (2007) who assume that consumers are differentiated only in their addresses and this data is imperfect. We consider two cases with respect to consumer heterogeneity in flexibility: relatively differentiated consumers and relatively homogeneous consumers. In the former case the behavior of non-cooperative profits as a function of data quality is similar to the behavior of non-cooperative profits in Liu and Serfes: The profits first decrease and then increase. When consumers are relatively homogeneous, the non-cooperative profits increase monotonically with the improvement in data quality, which makes it more difficult to sustain collusion with the improvement in quality of customer data compared to the case of relatively differentiated consumers. Our results support the findings of Liu and Serfes that collusion becomes more difficult to sustain with the improvement in data quality although we consider a different type of customer data: data on consumer flexibility.

Appendix

Proof Proposition 2. We characterize the collusive outcome under the first collusive scheme. Under collusion every firm acts as a monopolist on its own turf. If the basic consumer valuation is high enough, then every firm serves all consumers on its turf. The transportation cost parameter of the consumer on the segment m indifferent between buying from Firm A and not buying is

$$V - t^m x - p_A^C(x, m; n) = 0 \Longrightarrow \widetilde{t}^m = \frac{V - p_A^C(x, m; n)}{x}, \text{ where } \widetilde{t}^m \in [\underline{t}^m; \overline{t}^m].$$

$p_A^C(x, m; n)$ is the collusive price set by Firm A for a consumer on segment m with address x, given the quality of data is k and there are $n := 2^k$ segments. Firm A serves consumers with $t \leq \widetilde{t}^m$ for any address $x < 1/2$. The reason is that in each segment consumers with relatively low transportation cost parameters get positive utility when Firm A charges the collusive price, $p_A^C(x, m; n)$. As a monopolist, Firm A can extract a higher rent from them. Consumers with high transportation cost, $t > \widetilde{t}^m$, choose to not buy at all, otherwise they get a negative utility. The expected profit is

$$E[\pi_A^C(x, m; n) | x < 1/2] = p_A^C(x, m; n) \Pr\{t \leq \widetilde{t}^m\} = p_A^C(x, m; n) f_t \left(\frac{V - p_A^C(x, m; n)}{x} - \underline{t}^m \right).$$

Solving the maximization problem of Firm A w.r.t. $p_A^C(x, m; n)$ yields the condition on V, which guarantees that Firm A serves all consumers for any $x < 1/2$ on any segment m:

$$\text{if } V > \underline{t} x + \frac{x}{n}(\overline{t} - \underline{t})(m+1) \text{ then } p_A^C(x, m; n) = V - \left(\underline{t} + (\overline{t} - \underline{t}) \frac{m}{n} \right) x \text{ and } \widetilde{t}^m = \overline{t}^m.$$

The strongest condition implies $x = 1/2$, yielding $V > \underline{t}/2 + (\overline{t} - \underline{t})(m+1)/(2n)$. The collusive profit of Firm A is

$$\pi_A^C = \sum_{m=1}^{n} \int_0^{1/2} \int_{\underline{t}^m}^{\overline{t}^m} f_t p_A^C(x, m; n) dt dx = \frac{V}{2} - \frac{\underline{t}}{8} - \frac{(\overline{t} - \underline{t})(1+n)}{16n}.$$

Since two firms are symmetric, $\pi_B^C = \pi_A^C$.

We now characterize the optimal deviation strategy. If a firm deviates, it charges a different price only on the rival's turf. Consider a deviation by Firm B. The indifferent consumer on the turf of Firm A is characterized by the equation

$$V - tx - p_A^C(x, m; n) = V - (1 - x)t - p_B^D(x, m; n),$$

where $p_B^D(x, m; n)$ is the deviation price of Firm B on Firm A's turf. The consumer indifferent between buying from Firm A charging the collusive price and Firm B charging the deviation price is

$$\widehat{t}^m = \frac{V - p_B^D(x, m; n) - \overline{t}^m x}{1 - 2x}, \text{ where } \widehat{t}^m \in [\underline{t}^m; \overline{t}^m] \text{ and } x < 1/2.$$

Firm B serves consumers with $t \leq \widehat{t}^m$ for any address $x < 1/2$. The reason is that under deviation Firm B offers a lower price than the rival and the most flexible consumers find it attractive to switch since they have a low transportation cost. The expected deviation profit of Firm B is $E[\pi_B^D(x, m; n)|x < 1/2] = p_B^D(x, m; n) \Pr\{t \leq \widehat{t}^m\}$. Solving the maximization problem of Firm B we get the following condition, which guarantees that Firm B serves all consumers on Firm A's turf:

$$\begin{aligned} \text{if } V &> \underline{t}(1 - x) + \frac{(\overline{t} - \underline{t})}{n}(m(1 - x) + 1 - 2x), \\ \text{then } p_B^D(x, m; n) &= V - \left(\underline{t} + (\overline{t} - \underline{t})\frac{m}{n}\right)(1 - x) \text{ and } \widehat{t}^m = \overline{t}^m. \end{aligned}$$

The strongest condition implies $x = 0$, yielding $V > \underline{t} + (\overline{t} - \underline{t})(m + 1)/n$. The deviation profit of Firm B is

$$\begin{aligned} \pi_B^D &= \sum_{m=1}^{n} \left[\int_0^{1/2} \int_{\underline{t}^m}^{\overline{t}^m} f_t p_B^D(x, m; n) dt dx\right] + \pi_B^C(x > 1/2) \\ &= V - \frac{\underline{t}}{2} - \frac{(\overline{t} - \underline{t})(1 + n)}{4n}. \end{aligned}$$

Q.E.D.

Proof Proposition 3. We first characterize the collusive outcome under the second collusive scheme. Every firm acts as a monopolist on its turf and charges a monopoly price for any address on its turf which does not depend on the segment. Consider the turf of Firm A. For some $x < 1/2$ the transportation cost parameter of the consumer indifferent between buying at Firm A and not buying is

$$V - tx - p_A^C(x) = 0 \Longrightarrow \widetilde{t} = \frac{V - p_A^C(x)}{x}, \text{ where} \widetilde{t} \in [\underline{t}; \overline{t}].$$

Firm A serves consumers with $t < \widetilde{t}$, because only consumers with relatively low transportation costs get positive utility when Firm A charges the collusive price, $p_A^C(x)$. Its expected profit is

$$E[\pi_A^C(x)|x < 1/2] = p_A^C(x) \Pr\{t \leq \widetilde{t}\} = p_A^C(x) f_t \left(\frac{V - p_A^C(x)}{x} - \underline{t} \right).$$

We solve the maximization problem of Firm A w.r.t. $p_A^C(x)$. If the basic consumer valuation is large enough, Firm A serves all consumers on any segment on its turf:

$$\text{if } V > (2\bar{t} - \underline{t})x, \text{ then } p_A^C(x) = V - \bar{t}x \text{ and } \widetilde{t} = \bar{t}.$$

The strongest condition implies $x = 1/2$, yielding $V > \bar{t} - \frac{\underline{t}}{2}$. The collusive profit of Firm A is

$$\pi_A^C = \int_0^{1/2} \int_{\underline{t}}^{\bar{t}} f_t p_A^C(x) dt dx = \frac{V}{2} - \frac{\underline{t}}{8}.$$

Since two firms are symmetric, $\pi_B^C = \pi_A^C$.

Every firm deviates through acquiring customer flexibility data of quality k and discriminates among flexibility segments on both turfs. Consider the deviation by Firm B. The consumer indifferent between buying from Firm A or Firm B with some $x < 1/2$ on segment m is given by the equation

$$V - tx - p_A^C(x) = V - (1 - x)t - p_B^D(x, m; n),$$

where $p_B^D(x, m; n)$ is the deviation price of Firm B on Firm A's turf. Plugging in $p_A^C(x)$ into the above equation yields

$$\widehat{t}^m = \frac{V - p_B^D(x, m; n) - \bar{t}x}{1 - 2x}, \text{ where } \widehat{t}^m \in [\underline{t}^m; \bar{t}^m].$$

Firm B serves consumers with $t \leq \widehat{t}^m$, because their utility is higher when they buy from Firm B than from Firm A. The expected deviation profit of Firm B is $E[\pi_B^D(x, m; n)|x < 1/2] = p_B^D(x, m; n) \Pr\{t \leq \widehat{t}^m\}$. We solve the maximization problem of Firm B w.r.t. $p_B^D(x, m; n)$ and get that if the basic consumer valuation is large enough, then Firm B serves all consumers for

some $x < 1/2$ and some m:

$$\begin{aligned} \text{if } V &> \bar{t}x + (\underline{t} + (\bar{t} - \underline{t})\frac{m+1}{n})(1-2x), \\ \text{then } p_B^D(x,m;n) &= V - \bar{t}x - \left(\underline{t} + (\bar{t} - \underline{t})\frac{m}{n}\right)(1-2x) \text{ and } \widehat{t}^m = \overline{t}^m. \end{aligned}$$

The strongest condition implies $x = 0$, yielding $V > \underline{t} + (\bar{t} - \underline{t})(m+1)/n$.

We now compute the deviation prices of Firm B on it own turf. The indifferent consumer on the segment m for some $x > 1/2$ is characterized by the equation: $V - t(1-x) - p_B^D(x,m;n) = 0$. The transportation cost parameter of the consumer on the segment m indifferent between buying from Firm B and not buying is

$$\widehat{t}^m = \frac{V - p_B^D(x,m;n)}{1-x}, \text{ where } \widehat{t}^m \in [\underline{t}^m; \overline{t}^m].$$

Firm B stays a monopolist and serves consumers with $t \leq \widehat{t}^m$. The expected deviation profit of Firm B on its own turf is $E[\pi_B^D(x,m;n)|x > 1/2] = p_B^D(x,m;n)\Pr\{t \leq \widehat{t}^m\}$. We solve the maximization problem w.r.t. $p_B^D(x,m;n)$ and get that if the basic consumer valuation is large enough, then Firm B serves all consumers on some segment m and some address $x > 1/2$:

$$\begin{aligned} \text{if } V &> \left(\underline{t} + (\bar{t} - \underline{t})\frac{m+1}{n}\right)(1-x), \\ \text{then } p_B^D(x,m;n) &= V - \left(\underline{t} + (\bar{t} - \underline{t})\frac{m}{n}\right)(1-x). \end{aligned}$$

The strongest condition implies $x = 1/2$, yielding $V > \underline{t}/2 + (\bar{t} - \underline{t})(m+1)/(2n)$. The deviation profit of Firm B is

$$\begin{aligned} \pi_B^D &= \sum_{m=1}^{n} \int_0^{1/2} \int_{\underline{t}^m}^{\overline{t}^m} f_t p_B^D(x,m;n) dt dx + \sum_{m=1}^{n} \int_{1/2}^{1} \int_{\underline{t}^m}^{\overline{t}^m} f_t p_B^D(x,m;n) dt dx \\ &= V - \frac{\bar{t} + 3\underline{t}}{8} - \frac{3(\bar{t} - \underline{t})(1+n)}{16n}. \end{aligned}$$

Q.E.D.

Proof Proposition 4. Under the third collusive scheme firms agree not to acquire flexibility data and charge uniform competitive prices. We consider the case of our model with relatively differentiated consumers. Collusive prices and profits are a special case of non-cooperative equilibrium, with $k = 0$. In the equilibrium both firms follow a market-sharing strategy, where

Firm A sets the price $p_A^C(x|x<1/2)=2\bar{t}(1-2x)/3$ on its own turf and serves consumers with $t\in[\bar{t}/3;\bar{t}]$. On the rival's turf it charges $p_A^C(x|x>1/2)=\bar{t}(2x-1)/3$, and serves consumers with $t\in[0;\bar{t}/3]$. Firm B charges symmetric prices. The collusive profit is $\pi_i^C=5\bar{t}/36$, $i=\{A;B\}$.

Now, we turn to the deviation prices and profits. Suppose that Firm B deviates on A's turf by acquiring customer data ($n\geq 2$) and charging discriminatory prices. For $x<1/2$, the consumer indifferent between buying from Firm A or from Firm B is given by the condition:

$$V-tx-p_A^C(x|x<1/2)=V-(1-x)t-p_B^D(x,m;n)$$

where $p_B^D(x,m;n)$ is the deviation price of Firm B on Firm A's turf. Plugging $p_A^C(x|x<1/2)=2\bar{t}(1-2x)/3$ into the above equation we obtain the transportation cost parameter of the indifferent consumer:

$$\widehat{t}^m=\frac{2\bar{t}(1-2x)-3p_B^D(x,m;n)}{3(1-2x)}, \text{ where } \widehat{t}^m\in[\underline{t}^m;\bar{t}^m].$$

On the rival's turf Firm B serves consumers with relatively low transportation cost, $t\leq\widehat{t}^m$. Since consumers are relatively differentiated, there are always consumers who can switch brands costlessly. Therefore Firm B targets only the most flexible consumers of the rival. The expected deviation profit of Firm B is $E[\pi_B^D(x,m;n)|x<1/2]=p_B^D(x,m;n)\Pr\{t\leq\widehat{t}^m\}$. We solve the maximization problem of Firm B w.r.t. $p_B^D(x,m;n)$ taking into account that $\widehat{t}^m\in[\underline{t}^m;\bar{t}^m]$. We obtain the following results:

i) If $m<2n/3-1$, *then* $p_B^D(x,m;n)=(\bar{t}/3)(2-3m/n)(1-2x)$, *each firm follows a monopolization strategy on segment* m *and serves all consumers there.*

ii) If $m>2n/3-1$, *then* $p_B^D(x,m;n)=(\bar{t}/6)(2-3(m-1)/n)(1-2x)$, *Firm* B *follows a market-sharing strategy on the segment* m *and serves only consumers with* $t\in[\underline{t}^m;\bar{t}/3+\underline{t}^m/2]$.

Firm B optimally deviates on its own turf as well. For $x>1/2$ the transportation cost parameter of the indifferent consumer is derived from the following condition:

$$V-tx-p_A^C(x|x>1/2)=V-(1-x)t-p_B^D(x,m;n)$$

where $p_B^D(x,m;n)$ is the deviation price of Firm B on its own turf. Plugging $p_A^C(x|x>1/2)=$

$\overline{t}(2x-1)/3$ into the above equation we obtain:

$$\widehat{t}^m = \frac{3p_B^D(x,m;n) - \overline{t}(2x-1)}{3(2x-1)}, \text{ where } \widehat{t}^m \in [\underline{t}^m; \overline{t}^m].$$

On its own turf Firm B serves consumers with relatively high transportation cost, $t \geq \widehat{t}^m$. Since consumers are relatively differentiated, it prefers to lose the most flexible consumers to the rival because serving them is not profitable. The expected deviation profit of Firm B is $E[\pi_B^D(x,m;n)|x > 1/2] = p_B^D(x,m;n)\Pr\{t \geq \widehat{t}^m\}$. We solve the maximization problem of Firm B w.r.t. $p_B^D(x,m;n)$ taking into account that $\widehat{t}^m \in [\underline{t}^m; \overline{t}^m]$ and get that:
i) If $m < 2-n/3$, *then* $p_B^D(x,m;n) = (\overline{t}/6)(3m/n+1)(2x-1)$, *Firm B follows a market-sharing strategy on the segment* m *and serves only consumers with* $t \in [\overline{t}^m/2 - \overline{t}/6; \overline{t}^m]$.
ii) If $m > 2 - n/3$, *then* $p_B^D(x,m;n) = (\overline{t}/3)(2x-1)(3(m-1)/n+1)$ *and Firm B follows a monopolization strategy on the segment* m.

When $n = 2$ ($k = 1$) Firm B adopts a different deviation strategy. Since consumers are relatively differentiated, it prefers to lose the most flexible consumers, whose transportation cost parameter is $t \in [0; \overline{t}/12]$, to Firm A. Hence, if $m = 1$, Firm B adopts a market-sharing strategy and charges the price $p_B^D(x,1;2) = (5\overline{t}/12)(2x-1)$ to consumers with $t \in [\overline{t}/12; \overline{t}/2]$. If $m = 2$, Firm B adopts a monopolization strategy and charges the price $p_B^D(x,2;2) = (5\overline{t}/6)(2x-1)$ to consumers with $t \in [\overline{t}/2; \overline{t}]$. The total deviation profit, when $n = 2$ ($k = 1$), is

$$\pi_B^D = \int_0^{1/2}\int_0^{\overline{t}/3} f_t p_B^D(x,1;2)dtdx + \int_0^{1/2}\int_{\overline{t}/2}^{7\overline{t}/12} f_t p_B^D(x,2;2)dtdx$$

$$+\int_{1/2}^1\int_{\overline{t}/12}^{\overline{t}/2} f_t p_B^D(x,1;2)dtdx + \int_{1/2}^1\int_{\overline{t}/2}^{\overline{t}} f_t p_B^D(x,2;2)dtdx = \frac{17\overline{t}}{96}$$

If $n \geq 4$ ($k \geq 2$), then Firm B follows a monopolization strategy on every segment on its own turf. Thus, the total deviation profit is

$$\pi_B^D = \sum_{m=1}^{[\frac{2n}{3}-1]} \int_0^{1/2}\int_{\underline{t}^m}^{\overline{t}^m} f_t \frac{\overline{t}}{3}(2-\frac{3m}{n})(1-2x)dtdx + \sum_{m=[\frac{2n}{3}]}^{n} \int_0^{1/2}\int_{\underline{t}^m}^{\overline{t}(\frac{1}{3}+\frac{m-1}{2n})} f_t \frac{\overline{t}}{6}(2-3\frac{m-1}{n})(1-2x)dtdx$$

$$+\sum_{m=1}^{n} \int_{1/2}^1\int_{\underline{t}^m}^{\overline{t}^m} f_t \frac{\overline{t}}{3}(3\frac{m-1}{n}+1)(2x-1)dtdx$$

Q.E.D.

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