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Oren Bar-Gill

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Harvard Law School
Cambridge, MA 02138

Price Discrimination with Consumer Misperception

Oren Bar-Gill*

Harvard University

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Abstract

The rise of big data and sophisticated, machine learning algorithms is increasing the prevalence of price discrimination and even personalized pricing. In traditional models, where consumers' willingness-to-pay (WTP) is a function of preferences (and budget constraints), price discrimination is often celebrated for increasing efficiency albeit while reducing consumer surplus. This favorable view of price discrimination should be reevaluated when WTP is a function of both preferences and misperceptions. With demand-inflating misperceptions, price discrimination is even more harmful to consumers and might *reduce* efficiency. These results are derived using a simple, linear demand model with different levels of price discrimination (or segmentation). In the many consumer markets where misperception is common, more careful scrutiny of price discrimination is warranted.

Keywords: Price discrimination, segmentation, consumer misperceptions, behavioral economics, big data.

*William J. Friedman and Alicia Townsend Friedman Professor of Law and Economics, Harvard Law School, 1525 Massachusetts Ave., Cambridge, MA 02138, USA. Email: bargill@law.harvard.edu. For helpful comments and suggestions, I would like to thank Omri Ben-Shahar, Yochai Benkler, Ryan Bubb, Howell Jackson, Louis Kaplow, Alon Klement, Michael Meurer, Ariel Porat, Mark Ramseyer, Steve Shavell, Holger Spamann, Kathy Spier, Cass Sunstein, Rory Van Loo, David Walker, Kathy Zeiler, and workshop and conference participants at BU, Harvard and Tel-Aviv University, as well as the Editor and an anonymous referee. Haggai Porat and Emily Feldstein provided outstanding research assistance.

1 Introduction

The rise of big data and sophisticated, machine learning algorithms is increasing the prevalence of price discrimination. Sellers are increasingly able to fine-tune their pricing strategies, approaching the textbook ideal of perfect (first-degree) price discrimination or personalized pricing. In traditional models, where consumers' willingness-to-pay (WTP) is a function of preferences (and budget constraints), price discrimination is often celebrated for increasing efficiency albeit while reducing consumer surplus (see, e.g., Varian 1985). This favorable view of price discrimination should be reevaluated when WTP is a function of both preferences and misperceptions. In many markets, consumer misperceptions, especially demand-inflating misperceptions stoked by sellers' advertising campaigns, are common, and they affect WTP (see, e.g., Bar-Gill 2019). In these markets, price discrimination might reduce, rather than increase, efficiency, and it inflicts a greater harm on consumers as compared to the traditional models.

These results are derived using a simple, linear-demand model with different levels of price discrimination, which I formalize by allowing for different degrees of market segmentation (compare: Tirole 1988, pp. 137-139; Frank 2007, p. 404; Pindyck and Rubinfeld 2012, pp. 401-408). I first replicate the standard results that, without misperception, a higher degree of segmentation increases efficiency but reduces consumer surplus. I then add (demand-inflating) misperceptions and show that a higher degree of segmentation (i) may either increase or decrease efficiency, and (ii) reduces consumer surplus more than in the no misperception case.

The analysis in this Letter assumes an arguably common type of misperception that increases a consumer's WTP but without increasing the actual benefit that the consumer gains from the product or service. For example, consider a consumer who pays too much for a treadmill but ends up using it far less than anticipated. Or, moving from products to services, consider a consumer who pays too much for a health club subscription, because she overestimates the frequency with which she will attend the club (see DellaVigna and Malmendier 2006). As with experience goods or services, the consumer makes the purchase decision based on imperfect information and subject to misperception, but then realizes that the benefit is smaller than expected and regrets the purchase (or regrets paying too much for the product or service). (See, e.g., DellaVigna and Malmendier 2004; DellaVigna 2009; Grubb 2009.)

This Letter is intended as a first step towards incorporating consumer misperceptions into the analysis of price discrimination. The simple, linear-demand model in this Letter can be extended in different ways, and the literature on imperfect price discrimination has shown that results — regarding both efficiency and consumer surplus — can depend on the specific assumptions of the model (See Bergemann, Brooks and Morris 2015).

Following this Introduction, Section 2 presents the model. And Section 3 offers concluding remarks, summarizing the main results and policy implications, and suggesting possible extensions.

2 Model

2.1 Framework of Analysis

Consider a monopoly market with linear demand. Let Q denote quantity and P denote price. The inverse demand curve is: $P(Q) = \bar{P} - \alpha Q$, where α is the slope of the demand curve and $\bar{P}$ is the price above which demand is zero. Let $\bar{Q} = \bar{P}/\alpha$ denote the maximal quantity, obtained when $P = 0$. For simplicity, assume that the monopolist's per-unit cost is zero.[1]

We study the effects of increasing the level of price discrimination by comparing markets with more and less fine-tuned segmentation. To provide some intuition about how segmentation is modeled, consider a market with no segmentation or, equivalently, with a single segment covering all consumers — with WTP between zero and $\bar{P}$. Next, consider a market with two, equal-sized segments; the first segment includes consumers with WTP between $\frac{1}{2}\bar{P}$ to $\bar{P}$, and the second segment includes consumers with WTP between zero and $\frac{1}{2}\bar{P}$. Generally, in a market with N, equal-sized segments, the first segment includes consumers with WTP between $(1 - \frac{1}{N})\bar{P}$ to $\bar{P}$, and segment $n \in \{1, \ldots, N\}$ includes consumers with WTP between $(1 - \frac{n}{N})\bar{P}$ to $(1 - \frac{n-1}{N})\bar{P}$. (Note that the precise definition of the market segments will change, when consumer misperception is introduced in Subsection 2.3.)

2.2 No Misperception

To fix ideas, begin with the no-price-discrimination benchmark where the entire market is treated as a single segment. The monopolist will set a price, $P_1 = \frac{1}{2}\bar{P}$. Consumer surplus is: $CS_1 = \int_0^{\frac{1}{2}\bar{Q}}(P(Q) - P_1)dQ = \int_0^{\frac{1}{2}\bar{Q}}(P(Q) - \frac{1}{2}\bar{P})dQ$. Producer surplus is: $\Pi_1 = (\frac{1}{2}\bar{Q})P_1$. Overall welfare, the sum of the producer's surplus and the consumer surplus, is: $W_1 = CS_1 + \Pi_1 = \int_0^{\frac{1}{2}\bar{Q}} P(Q)dQ$; this is our measure of efficiency. The subscripts denote the number of segments. In the two-segment case, we have two prices: $P_2^1 = \frac{1}{2}\bar{P}$ and $P_2^2 = \frac{1}{4}\bar{P}$, where the superscripts denote the particular segment. In terms of consumer surplus, we have

[1] With a per-unit cost of $c > 0$, the analysis would be largely unchanged. We would define $\check{P} = \bar{P} - c$ and let $\check{Q} = \check{P}/\alpha$ denote the maximal quantity, obtained when $P = c$. For present purposes, a market with a demand curve $P(Q) = \bar{P} - \alpha Q$ and positive per-unit cost, c, is equivalent to a market with a demand curve $P(Q) = \check{P} - \alpha Q$ and zero per-unit cost. The analysis below would remain unaffected, except that we would need to replace $\bar{P}$ and $\bar{Q}$ with $\check{P}$ and $\check{Q}$ respectively. (And when considering misperceptions, we would add the misperception to the demand curve $P(Q) = \check{P} - \alpha Q$.) Of course, a higher cost reduces overall welfare and consumer surplus (as the monopolist increases the price), but the relative effects of price discrimination and of misperception remain the same.

$CS_2^1 = CS_1$ in segment #1, and $CS_2^2 = \int_{\frac{1}{2}\bar{Q}}^{\frac{3}{4}\bar{Q}} (P(Q) - P_2^2) dQ = \int_{\frac{1}{2}\bar{Q}}^{\frac{3}{4}\bar{Q}} (P(Q) - \frac{1}{4}\bar{P}) dQ$ in segment #2. Overall, we have: $CS_2 = CS_2^1 + CS_2^2 = CS_1 + \int_{\frac{1}{2}\bar{Q}}^{\frac{3}{4}\bar{Q}} (P(Q) - \frac{1}{4}\bar{P}) dQ$. In terms of producer surplus, we have $\Pi_2^1 = \Pi_1$ in segment #1, and $\Pi_2^2 = (\frac{1}{4}\bar{Q})P_2^2$ in segment #2. Overall, we have $\Pi_2 = \Pi_2^1 + \Pi_2^2 = \Pi_1 + (\frac{1}{4}\bar{Q})P_2^2$. In terms of welfare, we have $W_2^1 = W_1$ in segment #1, and $W_2^2 = CS_2^2 + \Pi_2^2 = \int_{\frac{1}{2}\bar{Q}}^{\frac{3}{4}\bar{Q}} P(Q) dQ$ in segment #2. Overall, we have: $W_2 = W_2^1 + W_2^2 = W_1 + \int_{\frac{1}{2}\bar{Q}}^{\frac{3}{4}\bar{Q}} P(Q) dQ$.

Generalizing to N segments, segment $n \in \{1, ..., N\}$ ranges from $\frac{n-1}{N}\bar{Q}$ to $\frac{n}{N}\bar{Q}$, and it includes consumers with WTP of $P(\frac{n-1}{N}\bar{Q}) = (1 - \frac{n-1}{N})\bar{P}$ to $P(\frac{n}{N}\bar{Q}) = (1 - \frac{n}{N})\bar{P}$. The size of the segment is: $\frac{n}{N}\bar{Q} - \frac{n-1}{N}\bar{Q} = \frac{1}{N}\bar{Q}$. The monopoly pricing for each segment is summarized in the following lemma.

Lemma 1: For all segments $n = 1, ..., N-1$, we have a corner solution: $P_N^n = (1 - \frac{n}{N})\bar{P}$. For the final segment, $n = N$, we have: $P_N^N = \frac{\bar{P}}{2N}$.

Proof: See Appendix.

We can now calculate the consumer surplus:

$$CS_N = \sum_{n=1}^{N-1} \left[\int_{\frac{n-1}{N}\bar{Q}}^{\frac{n}{N}\bar{Q}} \left(P(Q) - \left(1 - \frac{n}{N}\right)\bar{P} \right) dQ \right] + \int_{\frac{N-1}{N}\bar{Q}}^{\frac{2N-1}{2N}\bar{Q}} \left(P(Q) - \frac{1}{2N}\bar{P} \right) dQ = \tag{1}$$
$$(N-1)\left[\frac{1}{2N^2}\bar{Q}\bar{P}\right] + \left[\frac{1}{2(2N)^2}\bar{Q}\bar{P}\right] = \bar{Q}\bar{P} \cdot \frac{1}{8N^2} \cdot (4N-3)$$

The effects, on consumer surplus, of an increase in the degree of segmentation is given by:

$$CS_N - CS_{N-1} = \bar{Q}\bar{P} \cdot \frac{-(4N^2 - 10N + 3)}{8N^2(N-1)^2}$$

We see that $CS_N - CS_{N-1} < 0$ for all $N > 2$. A move from one segment to two segments increases the consumer surplus, but any further increase in the number of segments reduces consumer surplus. Also note that $CS_3 = CS_1$ and that for all $N > 3$ $CS_N < CS_1$.

Turning to producer surplus, we have:

$$\Pi_N = \sum_{n=1}^{N-1} \left[\frac{1}{N}\bar{Q} \cdot P\left(\frac{n}{N}\bar{Q}\right) \right] + \frac{1}{2N}\bar{Q} \cdot P\left(\frac{2N-1}{2N}\bar{Q}\right) = \bar{Q}\bar{P} \cdot \frac{2N^2 - 2N + 1}{4N^2} \tag{2}$$

The effects, on producer surplus, of an increase in the degree of segmentation is given by:

$$\Pi_N - \Pi_{N-1} = \bar{Q}\bar{P} \cdot \frac{2N^2 - 4N + 1}{4N^2(N-1)^2}$$

which is positive for all $N > 1$.

In terms of overall welfare, we have:

$$W_N = \int_0^{\left(1-\frac{1}{2N}\right)\bar{Q}} P(Q)dQ = \bar{Q}^2 \cdot \frac{1}{2}\alpha\left(1 - \frac{1}{4N^2}\right) \quad (3)$$

The effects, on overall welfare, of an increase in the degree of segmentation is given by:

$$W_N - W_{N-1} = \bar{Q}\bar{P} \cdot \frac{2N-1}{8N^2(N-1)^2}$$

which is positive for all $N > 1$.

We have replicated the standard results, which are summarized in the following proposition.

Proposition 1: Without misperception, a higher degree of price discrimination increases efficiency and reduces consumer surplus.

Remark. The monopolist will seek to increase the degree of price discrimination, by increasing the number of segments from *N-1* to *N*, as long as $\Pi_N - \Pi_{N-1}$ exceeds the cost of acquiring the additional information needed to increase the number of segments. Note that while the difference $\Pi_N - \Pi_{N-1}$ is always positive, it is decreasing in *N*, namely, the extra profit from additional segmentation is decreasing in *N*. This means that, at some point, the monopolist may decide that the extra profit from additional segmentation does not justify the cost of acquiring the information needed for the additional segmentation.

2.3 Misperception

For ease of exposition, I consider a fixed level of misperception, δ, common to all buyers. Such misperception leads to an upward shift of the (inverse) demand curve. This new demand curve, which I will call the perceived demand curve, is: $\hat{P}(Q) = (\bar{P} + \delta) - \alpha Q$. Let $\tilde{P} \equiv \bar{P} + \delta$ and $\tilde{Q} \equiv (\bar{P} + \delta)/\alpha$. Market segmentation is based on WTP, which now has a misperception-based component. For example, in a market with two segments, segment #1 includes consumers with WTP between $\frac{1}{2}\tilde{P}$ to $\tilde{P}$; and segment #2 includes consumers with WTP between 0 and $\frac{1}{2}\tilde{P}$.

To fix ideas, begin with the no-price-discrimination benchmark where the entire market is treated as a single segment. The monopolist will set a price, $P_1 = \frac{1}{2}\tilde{P}$. Consumer surplus is $CS_1 = \int_0^{\frac{1}{2}\tilde{Q}}(P(Q) - P_1)dQ = \int_0^{\frac{1}{2}\tilde{Q}}(P(Q) - \frac{1}{2}\tilde{P})dQ$. Producer surplus is: $\Pi_1 = (\frac{1}{2}\tilde{Q})P_1$. Overall welfare is: $W_1 = CS_1 + \Pi_1 = \int_0^{\frac{1}{2}\tilde{Q}} P(Q)dQ$. In the two-segment case, we have two prices: $P_2^1 = \frac{1}{2}\tilde{P}$ and $P_2^2 = \frac{1}{4}\tilde{P}$. In terms of consumer surplus, we have $CS_2^1 = CS_1$ in segment #1, and $CS_2^2 = \int_{\frac{1}{2}\tilde{Q}}^{\frac{3}{4}\tilde{Q}}(P(Q) - P_2^2)dQ = \int_{\frac{1}{2}\tilde{Q}}^{\frac{3}{4}\tilde{Q}}(P(Q) - \frac{1}{4}\tilde{P})dQ$ in segment #2. Overall, we have: $CS_2 = CS_2^1 + CS_2^2 = CS_1 + \int_{\frac{1}{2}\tilde{Q}}^{\frac{3}{4}\tilde{Q}}(P(Q) - \frac{1}{4}\tilde{P})dQ$. In terms of producer surplus, we have $\Pi_2^1 = \Pi_1$ in segment #1, and $\Pi_2^2 = (\frac{1}{4}\tilde{Q})P_2^2$ in segment #2. Overall, we have: $\Pi_2 = \Pi_2^1 + \Pi_2^2 = \Pi_1 + (\frac{1}{4}\tilde{Q})P_2^2$. In terms of welfare, we have $W_2^1 = W_1$ in segments #1, and $W_2^2 = CS_2^2 + \Pi_2^2 = \int_{\frac{1}{2}\tilde{Q}}^{\frac{3}{4}\tilde{Q}} P(Q)dQ$. Overall, we have: $W_2 = W_2^1 + W_2^2 = W_1 + \int_{\frac{1}{2}\tilde{Q}}^{\frac{3}{4}\tilde{Q}}(Q)dQ$.

Generalizing to N segments, we have:

$$
\begin{aligned}
CS_N &= \sum_{n=1}^{N-1}\left[\int_{\frac{n-1}{N}\tilde{Q}}^{\frac{n}{N}\tilde{Q}}\left(P(Q) - \left(1 - \frac{n}{N}\right)\tilde{P}\right)dQ\right] + \int_{\frac{N-1}{N}\tilde{Q}}^{\frac{2N-1}{2N}\tilde{Q}}\left(P(Q) - \frac{1}{2N}\tilde{P}\right)dQ \\
&= (N-1)\left[\frac{1}{2N^2}\tilde{Q}\tilde{P} - \frac{1}{N}\tilde{Q}\delta\right] + \left[\frac{1}{2(2N)^2}\tilde{Q}\tilde{P} - \frac{1}{2N}\tilde{Q}\delta\right] = \tilde{Q}\tilde{P}\cdot\frac{1}{8N^2}\cdot(4N-3) - \tilde{Q}\delta\cdot\frac{2N-1}{2N}
\end{aligned} \tag{4}
$$

The effects, on consumer surplus, of an increase in the degree of segmentation is given by:

$$CS_N - CS_{N-1} = \tilde{Q}\tilde{P}\cdot\frac{-(4N^2 - 10N + 3)}{8N^2(N-1)^2} - \tilde{Q}\delta\cdot\frac{1}{2N(N-1)}$$

We know from Section 2.2 that $\tilde{Q}\tilde{P}\cdot\frac{-(4N^2-10N+3)}{8N^2(N-1)^2}$ is negative for all $N > 2$. Since $-\tilde{Q}\delta\cdot\frac{1}{2N(N-1)} < 0$ for all $N > 1$, $CS_N - CS_{N-1} < 0$ for all $N > 2$ (and when $\delta > \frac{1}{7}\bar{P}$, $CS_N - CS_{N-1} < 0$ also for $N = 2$). Also note that for all $N \geq 3$ $CS_N < CS_1$. More important, $|CS_N - CS_{N-1}|$ is increasing in δ, namely, the reduction in consumer surplus is greater when the degree of misperception is higher.

Turning to producer surplus, we have:

$$\Pi_N = \sum_{n=1}^{N-1}\left[\frac{1}{N}\tilde{Q}\cdot\hat{P}\left(\frac{n}{N}\tilde{Q}\right)\right] + \frac{1}{2N}\tilde{Q}\cdot\hat{P}\left(\frac{2N-1}{2N}\tilde{Q}\right) = \tilde{Q}\tilde{P}\cdot\frac{2N^2 - 2N + 1}{4N^2} \tag{5}$$

The effects, on producer surplus, of an increase in the degree of segmentation is given by:

$$\Pi_N - \Pi_{N-1} = \tilde{Q}\tilde{P}\cdot\frac{2N^2 - 4N + 1}{4N^2(N-1)^2}$$

which is positive for all $N > 1$.

In terms of overall welfare, we have:

$$W_N = \int_0^{(1-\frac{1}{2N})\tilde{Q}} P(Q)dQ = \tilde{Q}^2 \cdot \frac{1}{2}\alpha \left(1 - \frac{1}{4N^2}\right) - \left(1 - \frac{1}{2N}\right) \tilde{Q}\delta \tag{6}$$

The effects, on overall welfare, of an increase in the degree of segmentation is given by:

$$\begin{aligned} W_N - W_{N-1} &= \tilde{Q}\tilde{P} \cdot \frac{2N-1}{8N^2(N-1)^2} - \tilde{Q}\delta \frac{1}{2N(N-1)} \\ &= \tilde{Q} \cdot \frac{1}{8N^2(N-1)^2} \cdot \left(\bar{P}(2N-1) - (4N^2 - 6N + 1)\delta\right) \end{aligned}$$

We see that $W_N - W_{N-1} < 0$ when $\delta > \frac{\bar{P}(2N-1)}{4N^2-6N+1}$.

We can now state the effects of price discrimination.

Proposition 2: With misperception –

(a) For low levels of misperception, $\delta < \hat{\delta} \equiv \frac{\bar{P}(2N-1)}{4N^2-6N+1}$, a higher degree of price discrimination increases efficiency. For high levels of misperception, $\delta > \hat{\delta}$, a higher degree of price discrimination reduces efficiency. The threshold, $\hat{\delta}$, is decreasing in N.

(b) A higher degree of price discrimination reduces consumer surplus. This reduction is increasing in the level of misperception.

In a market without misperception, price discrimination increases efficiency by reducing the monopoly deadweight loss (Proposition 1). With demand-inflating misperception ($\delta > 0$), the deadweight loss is smaller even without price discrimination, and a higher level of price discrimination might result in inefficient purchases. In terms of consumer surplus, price discrimination allows the seller to more effectively exploit consumers' inflated demand. More consumers end-up losing from the purchase, thus reducing the consumer surplus. Note that without misperception consumers gain less when sellers price-discriminate, but they do not lose. With misperception, price discrimination results in affirmative losses.

Remark. A higher degree of price discrimination increases producer surplus, and the increase is larger for higher levels of misperception. The monopolist will seek to increase the degree of price discrimination, by increasing the number of segments from *N-1* to *N*, as long as $\Pi_N - \Pi_{N-1}$ exceeds the cost of acquiring the additional information needed to increase the number of segments. With higher levels of misperception, the monopolist will invest more in acquiring the information needed to achieve greater segmentation. Indeed, we can expect more segmentation in markets with demand-inflating misperception.

3 Concluding Remarks

3.1 Summary and Policy Implications

This Letter studied the effects of price discrimination on efficiency and consumer surplus, when consumers suffer from demand-inflating misperceptions. The existence of such misperceptions merits a reconsideration of standard results about the effects of price discrimination. In particular, price discrimination is more harmful to consumers and might not even have the countervailing benefit of increased efficiency; indeed, it might reduce efficiency. Policymakers should exercise greater scrutiny of price discrimination in markets where misperception is prevalent. Competition authorities and regulators charged with enforcing consumer protection laws should consider the interactions between price discrimination and consumer misperception that this Letter begins to develop. And, since higher levels of price discrimination rely on big data, privacy and data security laws may also be implicated.

3.2 Extensions

The basic model used in this Letter can be extended in different ways. The linear-demand framework should be replaced with a more general demand function. An oligopoly model should be explored, in addition to the monopoly model utilized in this Letter (see Bar-Gill 2020 for a first step in this direction). And heterogeneous misperception levels should be considered.

A note on heterogeneous misperceptions: The analysis compared the no-misperception case to a common, uniform misperception case. How would the results change if some consumers suffer from misperception but others don't or, more generally, if the level of misperception varies among consumers? While a comprehensive analysis of the heterogeneous misperception case is beyond the scope of this Letter, a few observations can be offered. The monopolist cares about WTP; it does not care about whether a high WTP is the result of the consumer's preferences or misperceptions. The prevalence and (heterogeneous) levels of misperception do affect consumer surplus and overall welfare. If some consumers suffer from misperception but others don't, then we would expect results that are in between those stated in Propositions 1 and 2. (Note that since the monopolist does not care about whether a high WTP is the result of the consumer's preferences or misperceptions, the monopolist would not invest resources in trying to distinguish between consumers whose high WTP is the result of misperceptions and those whose high WTP is the result of preferences. And if the monopolist, without investing, has information that allows it to make this distinction, it would not make use of this information in devising its segmentation and pricing strategy.)

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Appendix

Proof of Lemma 1

A monopolist in segment n, faces the following profit function:

$$\pi(P) = \begin{cases} 0, & P \geq \left(1 - \frac{n-1}{N}\right)\bar{P} \\ P \cdot \left(\frac{\bar{P}-P}{\alpha} - \frac{n-1}{N}\bar{Q}\right), & P \in \left(\left(1 - \frac{n}{N}\right)\bar{P}, \left(1 - \frac{n-1}{N}\right)\bar{P}\right) \\ P \cdot \frac{1}{N}\bar{Q}, & P \leq \left(1 - \frac{n}{N}\right)\bar{P} \end{cases}$$

Focusing on the intermediate range, we get the FOC: $\pi'(P) = \frac{\bar{P}}{\alpha}\left(1 - \frac{n-1}{N}\right) - \frac{2P}{\alpha} = 0$, and thus the internal optimum is: $P^* = \frac{\bar{P}}{2}\left(1 - \frac{n-1}{N}\right)$. But this price is outside the $P \in \left(\left(1 - \frac{n}{N}\right)\bar{P}, \left(1 - \frac{n-1}{N}\right)\bar{P}\right)$ range, specifically $P^* \leq \left(1 - \frac{n}{N}\right)\bar{P}$, for all $n \leq N-1$. Therefore, for all segments $n = 1, \ldots, N-1$, we have a corner solution: $P_N^n = (1 - \frac{n}{N})\bar{P}$. For the final segment, $n = N$, we have: $P_N^N = \frac{\bar{P}}{2N}$.

QED