When is Fruit Bundling Fruitless?

Sorting, Bundling and Disposal when

Quality Information is Asymmetric

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Abstract

This paper examines the conditions in which it is profitable for sellers to allow consumer sorting of goods for quality in an asymmetric information framework. It is shown that by allowing consumers to sort goods, sellers can quality discriminate, a practice described in this paper, in which higher quality goods are assigned to consumers who have weaker preferences for quality. If sellers are obligated to clear the market with a single price for goods of heterogeneous quality, quality discrimination raises the market clearing price by reducing the price sensitivity of marginal consumers, even though the practice lowers the total surplus to trade. Alternatively, when quality information is asymmetric, sellers may opt not to clear the market. This paper considers the role of retailer disposal as a quality improvement mechanism and considers its implications for wholesale versus retail demand when alternative quality improvement mechanisms are developed.

I Introduction

Goods often vary substantially in quality but are priced as commodities. In this setting, consumers exert time and effort to identify goods of higher quality. For example, shoppers in grocery stores examine produce and meat for differences in smell or appearance, and buyers of second-hand products such as clothes or cars thoroughly inspect those goods for defects or damage. Barzel (1977) argues that consumer sorting dissipates the value of trade if all consumers value quality equally. Sorting is costly, but because it only reassigns goods across consumers, it cannot create any new benefits in aggregate. Barzel argues that sellers will design marketing structures that prevent opportunistic sorting by consumers. For example, fruit may be bagged or otherwise sold in pre-bundled packages. Supermarket attendants may be assigned to disperse goods rather than having consumers select them. In labor markets, receptionists may assign workers to specific jobs with doctors or dentists being assigned to patients or mechanics being assigned to cars.

Barzel asserts that sorting is valueless when consumers value goods of varying quality equally. If consumers are prevented from sorting, the product sells at a price reflecting the average quality. If consumers are allowed to sort, the product sells at a price reflecting the average quality reduced by the cost of sorting. Because consumers value quality equally, there are no potential gains in allocative efficiency by identifying quality differences. As long as consumers are relatively risk neutral, there are no benefits to quality identification.

In most instances, consumers are not homogenous in their demands for quality. Goods may still sell at a single price, however, if sellers cannot identify quality at a low cost. For example, quality differences of fruits and vegetables may not becomes apparent until after the goods are displayed. Alternatively, clothing has a large fashion component which sellers may be unable to identify. In this environment, sellers may price goods uniformly even though the goods are known to vary in quality.

When consumers can identify higher quality goods that are priced identically, they can improve their individual surplus by sorting. While individually rational, sorting does not increase the total consumer surplus in aggregate because the remaining distribution of goods falls in average quality. Sorting skims off the highest quality goods and truncates the remaining distribution of quality. To clear the market, sellers must lower the price for consumers who do not sort goods since they receive a lower expected quality. Sellers cannot expropriate the additional benefits that accrue to consumers who sort goods unless they can identify those consumers beforehand and charge them a higher price.

When consumers are heterogeneous, identifying quality differences in goods is socially valuable because allocative efficiency and the size of the total surplus to trade depends on which consumers are assigned goods of differing quality. Consumer sorting reveals quality information. If allowing consumer sorting ensures that higher quality goods are allocated to consumers with stronger preferences for quality, the practice increases the gains from trade even though sellers may not profit from it. Conversely, if allowing consumer sorting ensures that higher quality goods are allocated to consumers with weak preferences for quality, the gains from trade are reduced. This paper shows that even when the second case holds, sellers may still allow consumer sorting if they are constrained to charge all consumers a single price. Sellers constrain sorting in order to quality discriminate, a strategy in which higher quality goods are assigned to lower value consumers to reduce the price sensitivity of these consumers. To accomplish quality discrimination, weak valuations of quality must be correlated with low sorting costs across consumers. This relationship ensures that consumers who receive higher quality by sorting goods are those who were previously most sensitive to price increases.

In contrast to Barzel's results, this paper's findings rest critically on the heterogeneity of consumers in their quality preferences and search costs and on the constraint that sellers must clear the market at a single price. An alternative situation is also considered in which sellers do not clear the market but instead a discard a portion of their goods once they have been sorted through by consumers. The commitment by sellers to dispose of lower quality goods has the effect of raising the expected quality of the good. In a comparative static framework, it is shown that disposal can increase seller profits when consumer preferences are heterogeneous, sorting costs are low, and wholesale prices are low relative to resale prices.

II Literature Review

Barzel (1982) argues that when all consumers value quality equally, sellers will try to prevent consumers from sorting goods because it dissipates the value of trade. Sorting creates a fallacy of composition because while individual consumers can improve the quality of their purchase through sorting, consumers in aggregate cannot. When all consumers sort goods, the market clearing price to falls by the cost of sorting. When only a portion of consumers sort, the market clearing price still falls because consumers who do not sort receive a good of lower expected quality (as it is drawn from a truncated quality distribution.)

To discourage this behavior, several authors have argued that consumer sorting may be prohibited or discouraged in several innocuous ways. Barzel (1982) asserts that produce such as apples or potatoes can be bundled randomly so that consumers cannot sort those goods for blemishes. Kenney and Klein (1983) apply this same argument to the marketing of diamonds. Typically, diamonds are sold in unopened packages containing many diamonds. Buyers may inspect a package, but doing so typically eliminates the possibility of future trade between buyer and seller. The authors argue that randomly bundling diamonds reduces the variance in values of packages which removes the incentive for buyer inspection, a very costly action.

Kenney and Klein argue that block booking of movies in first run theaters is also an attempt to prevent buyers from sorting goods. After movies are exhibited, their quality quickly becomes common knowledge to buyers and sellers. If all movies are priced identically, buyers attempt to reject movies once they are revealed to be of a lower quality. Rejection of movies causes costly rescheduling and renegotiation without necessarily adding value to the transaction. By bundling movies and contracting prior to quality discovery, distributors lower the variance in quality of any given bundle of movies. Losses from unexpectedly bad movies approximately equal the gains from unexpectedly good movies.

Leffler, Malishka, and Rucker (2001) consider the alternative cases where fruit and vegetables are priced per unit (by-the-each) or per pound (by-the-pound). Fruit priced by-the-pound eliminates the incentive for consumers to sort through goods to find the larger items but forces cashiers to weigh the produce, which is more time consuming than simply counting it. They find that produce is more likely to be sold per pound when it has a larger variance in size or a larger total value (per pound). Alternatively, goods are more likely to be sold per unit when the dispersion in customer values of goods is greater.

Sellers may attempt to restrict sorting in other ways. For instance, an attendant may be stationed to disperse goods, such as produce at a supermarket or mechanic services at an auto-repair shop, rather than allowing consumers to select goods. A portion a good's inventory may be withheld from the store shelf to reduce the gains from sorting. Goods may be delivered to the buyer rather than allowing consumers to pick their own as in the case of lumber.

In other cases, however, sorting is seemingly encouraged. For example, premium grocery stores and specialty markets, such as pick-your-own-strawberry patches, encourage sorting. Sellers may charge a premium to allow consumers to sort, which provides them with a higher quality good. If sellers cannot identify quality differences inexpensively, allowing consumers to sort goods may effectively improve the average quality received by sorting consumers. Moreover, if sellers pre-commit to discarding a fixed portion of goods once consumers have sorted out the best goods, they effectively raise the goods expected quality.

A typical supermarket discards approximately 6-7% of its produce outside of the primary market.[1] At premium supermarkets, this figure may be twice as high. This figure varies across items depending on their durability and perishability. For instance, disposal rates are lower for potatoes and cabbage and higher for bananas, tomatoes and

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[1] Personal communication with Ed Estes, a former produce buyer for a large supermarket chain and a professor in the department of Agricultural and Resource Economics at North Carolina State University

melons. When these goods are unsold, they may be sold at a reduced price or donated to a food bank, but often they are simply hauled off as refuse. While seller disposal may be influenced by many factors, this paper focuses on the motivation of increasing the expected quality of a good by removing the lower end of the quality distribution. By pre-committing to discard a certain percentage of goods after they are sorted, sellers raise the good's expected value for any individual purchase.

Consumers are assumed to make their purchasing decision based on their expectation of the quality of goods at a store which is conditional on the percentage of goods discarded. Consumers associate higher quality with a store that replenishes its shelves when only the bottom 20% of the goods remain over a store that replenishes its shelves when only the bottom 5% of the goods remain. In practice, distinguishing whether reductions in the quality of produce over time are the result of sorting, which truncates the quality distribution but does not change each product's underlying quality, or of decay, which reduces the quality of all goods, is difficult. However, if decay is not uniform across goods, consumers still sort goods based on their state of deterioration. So, decay, due to natural processes or consumer handling, may create the natural asymmetry in information that this paper address because sellers cannot identify which goods will deteriorate when they establish their prices.

III The Vertical Differentiation Model of Demand

The vertical differentiation model of demand described by Mussa and Rosen (1977) and Laffont and Martimort (2002) has been used extensively to consider goods in which all consumers agree on the quality ordering of goods but are heterogeneous in their willingness to pay for quality. In this model, consumers purchase a single good and receive the following indirect utility:

$$U(\theta_i, q) = \theta_i q - p \qquad (1)$$

The variable θ_i measures the i^{th} buyer's preference for quality so that a consumer with a higher θ values quality more. Across consumers, the θ_i's are distributed according to the probability distribution function $f(\theta)$ over the support $(0, \overline{m})$.[2]

Across goods, quality is distributed according to the probability distribution function $g(q)$ with mean μ and a positive support. While sellers (retailers) can adjust sales wholesale volume at constant unit wholesale cost of c, the production of quality is stochastic. The variance in quality is assumed to be independent of the sales volume. For example, a supermarket can order more apples from a supplier, but the variance in apple quality does not change if more apples are ordered. Consumers are assumed to be risk neutral, so that purchases are based on average expected quality if they are prevented from sorting goods.

III.A Bundling to Inhibit Sorting

Bundling, pricing per pound, and other strategies that inhibit consumer sorting essentially ensure that all consumers expect to receive a good of average quality rather than a good drawn from a truncated quality distribution. With bundling, each consumer expects to receive a good of quality μ since they cannot easily pick out a better good. Essentially, bundling replicates the outcome that would occur if goods were randomly distributed without regard for quality.

[2] It is necessary that θ be distributed over a strictly positive support since higher quality is preferred by all consumers.

Let M represent the total number of possible consumers who may purchase the good and N represent the total volume of wholesale goods marketed through the retail outlet. For simplicity, assume that wholesale goods are supplied perfectly elastically at price c. For consumers to purchase a bundled good with expected quality μ, the good must be priced so that consumers receive a positive utility. In this case, a consumer purchases the good if:

$$\theta_i \geq \tfrac{P}{\mu} \tag{2}$$

The portion of consumers who purchase the good is the portion of consumers whose θ values exceed $\frac{P}{\mu}$. This portion is equal to $1 - F(\frac{P}{\mu})$ where $F(\theta)$ is the cumulative distribution function of θ. The demand for the good is the market size multiplied by the proportion of consumers who purchase or:

$$D(P) = M \times \left(1 - F\left(\tfrac{P}{\mu}\right)\right) \tag{3}$$

Market clearing implies that retail demand, $D(P)$, is equal to wholesale supply, N. The market clearing price is:

$$P = \mu F^{-1}(1 - \tfrac{N}{M}) \tag{4}$$

and seller profits are:

$$\Pi = \left(\mu F^{-1}(1 - \tfrac{N}{M}) - c\right)N \tag{5}$$

If $f(\theta)$ is the uniform distribution over $(0,m)$, then the profits are

$$\Pi = \left(\mu m(1 - \tfrac{N}{M}) - c\right)N \tag{6}$$

Solving the first-order conditions shows that the optimal price, quantity and profit in equilibrium are:

$$P' = \frac{M}{2} \tag{7}$$

$$N' = (\mu m - c)\frac{M}{2\mu m} \tag{8}$$

$$\Pi' = (P - c)N = (\mu m - c)\frac{M^2}{4\mu m} - c(\mu m - c)\frac{M}{2\mu m} \tag{9}$$

III.B Perfect Quality Discrimination when Sellers can Identify Quality and θ

In some cases, sellers may be able to identify quality differences in their own product, but be unable to charge separate prices for goods of different quality. If sellers have specific knowledge of each consumer's θ_i, but can charge only a single price, then they can potentially increase revenues by adjusting the assignment of qualities to different consumers.

An example would be that of a pastry chef who knows the quality of all her pastries and has intimate knowledge of all her customers. If the chef knows a customer is marginal in his decision to purchase – he does not like pastries or he has a small income – she may instead offer that customer the best pastries rather than just randomly selecting them off the shelf. Other customers – who purchase pastries regularly and can be relied upon to buy the good regardless of its quality – will receive the remaining pastries that are necessarily of a lower quality. The pastry chef might alternatively have offered the customers different prices and in that case, the eventual assignment of quality would likely be reversed so that regular customers who will pay more for higher quality receive the better pastries while borderline customers get the marginal goods but pay a reduced price.

Assigning higher quality goods to consumers who value quality less occurs because the seller cannot charge these consumers different prices. The process whereby sellers assign different qualities across consumers in order to reduce the price sensitivity of marginal consumers when they are obligated to charge a single price is introduced as quality discrimination. Unlike perfect price discrimination, which is efficient in both production and allocation, quality discrimination is extremely inefficient in terms of allocation. Under quality discrimination, the highest quality goods are distributed to the consumers who value them least, the consumers with the lowest valuation of quality.

Assuming supply is fixed and equal to N', the quantity from equation (8). If those same goods were distributed according to the decision rule, $q(\theta_i)$, which assigns individual consumers goods of quality q based on their θ_i, then the maximization problem for sellers is as follows:

$$\max_{P,q(\theta)}(P-c)*N' \text{ subject to } \theta_i q(\theta_i)-P\geq 0 \quad (9)$$

It is clear from this specification that the assignment of quality will proceed according to the following rule:

$$q(\theta_i)\geq P/\theta_i \quad (10)$$

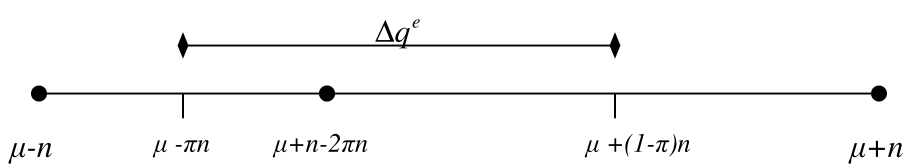
So, the optimal distribution rule is to assign higher quality goods to consumers who value quality less. The actual price that sellers can charge in equilibrium is bound by the distributions of quality and consumer preferences, but the pattern of assignment remains the same: consumers with stronger preferences for quality receive lower quality products.

For example, there are two types of baseball fans – diehard and fair-weather. Diehard fans love seeing baseball games and have high preferences for quality. They will pay $65 for a front row seat and $35 for an upper deck seat, which is far from the field. Fair weather fans are largely indifferent to seeing baseball games and do not appreciate improvements in quality like diehard fans do. Fair weather fans will pay $40 for a front row seat and $20 for an upper deck seat. If allowed to charge separate prices, sellers make $85 by charging $65 for front row seats and $20 for upper deck seats. If sellers cannot charge separate prices for different seats and they cannot identify fans by type, they will sell all seats at a price of $65 and a portion of the seats will go unsold. Sellers make only $65. If sellers still cannot charge separate prices but they can identify fans by type, all tickets will sell at a price of $35 dollars, but now fair weather fans will sit in the front row and diehards will sit in the upper deck. Sellers will now make $70 from ticket sales. Notice, the only way to induce fair weather fans to pay the higher price of tickets is to offer them a higher quality. This redistribution of quality, however, assigns the best seats to the fan type that appreciates them least. It is easy to construct opportunities for market improvement such as fair weather fans and diehards exchanging tickets for a price between $30 and $15. But if legal restrictions, information problems (tickets do not state where they are in the stadium), or high transactions costs prevent trade in secondary markets, the initial distribution remains.

III.C Market Clearing under Asymmetric Information with Sorting

Often, consumers can detect goods by quality when sellers cannot. Asymmetric information may emerge when quality differences do not emerge until after goods are displayed, when quality testing is expensive for sellers, or goods have a large fashion element of which sellers are unaware. When consumers sort goods, they incur an individual specific fixed cost. This cost is denoted as λ_i and it is jointly distributed with θ_i across all consumers according to the joint distribution function $f(\theta,\lambda)$. The consumer preference for quality variable, λ_i, is distributed over positive range 0 to l.

In sorting, consumers trade off the value of a higher quality and the sorting cost, λ_i. To simplify the analysis, consumers who sort goods are assumed to received the expected quality of sorted goods. Let q_s^e be the expected quality of sorted goods and q_n^e be the expected quality of goods that are not sorted. Let π be the proportion of buyers who sort goods. The expected quality of sorted goods, q_s^e, is the expected quality of the upper π portion of the quality distribution. The expected quality of goods not sorted, q_n^e, is the expected quality of the lower 1-π portion of the quality distribution. The notation Δq^e denotes $\left(q_s^e - q_n^e\right)$, the difference in quality between sorted and non-sorted goods. If quality is distributed uniformly between $\mu+n$ and $\mu+n$, then the expected quality of sorted goods, q_s^e, is equal to $\mu+(1-\pi)n$, the expected quality of non-sorted goods, q_n^e, is equal to $\mu-\pi n$, and the difference in expected quality between to two, Δq^e, is equal to n. These specifications are depicted on the graph below.



Buyers sort goods if the value of sorted goods exceeds both their reservation utility and the value they receive from unsorted goods. These two requirements are the individual rationality (IR) and incentive compatibility (IC) constraints respectively. As is common with adverse selection models, the IR constraint is not binding for consumers choosing the high quality sorted good while the IC constraint is not binding for consumers buying the low quality non-sorted good. The IR constraint below is very similar to equation (2):

$$\theta_i \geq \frac{P}{q_n^e} \qquad \text{(IR)} \qquad (13)$$

The incentive compatibility constraint is as follows

$$\theta_i q_s^e - P - \lambda_i \geq \theta_i q_n^e - P \qquad \text{(IC)} \qquad (14)$$

$$\theta_i \geq \frac{\lambda_i}{\Delta q^e} \qquad \text{(IC)} \qquad (15)$$

The incentive compatibility constraint shows that only the π portion of buyers whose θ_i exceeds $\lambda_i / \Delta q^e$ will sort goods. The remaining (1- π) portion of consumers must have θ_i both greater than P/q_n^e to ensure that they receive a positive surplus, but less than $\lambda_i / \Delta q^e$ since they do not sort.

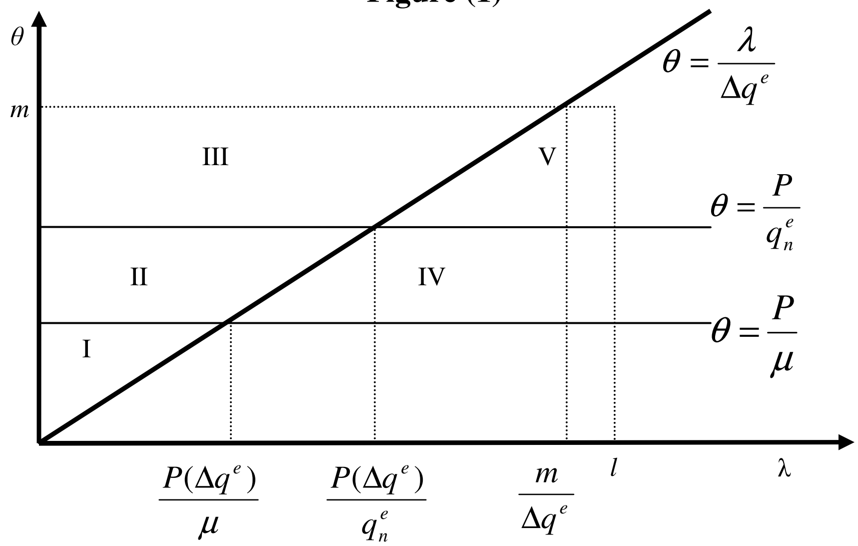
III.D Comparing the Sorting and Bundling Equilibriums

It is now possible to evaluate whether seller revenue is higher when consumers are prevented from sorting goods or, alternatively, whether bundling fruit is profitable. Figure (1) divides the joint distribution of θ and λ into several regions in the case where *l* is less than Δq^e[3]. If sorting goods is permitted, buyers with θ greater than $\lambda / \Delta q^e$ purchase sorted goods, while buyers with θ values between $\lambda / \Delta q^e$ and P/q_n^e purchase unsorted goods. If goods are sold bundled so the consumers receive goods of average quality μ, only buyers with θ values greater than P/μ purchase the product. So, when sorting is allowed, consumers in regions II, III, IV, and V purchase the good.

[3] The case where *l* is greater than Δq^e is in Appendix A

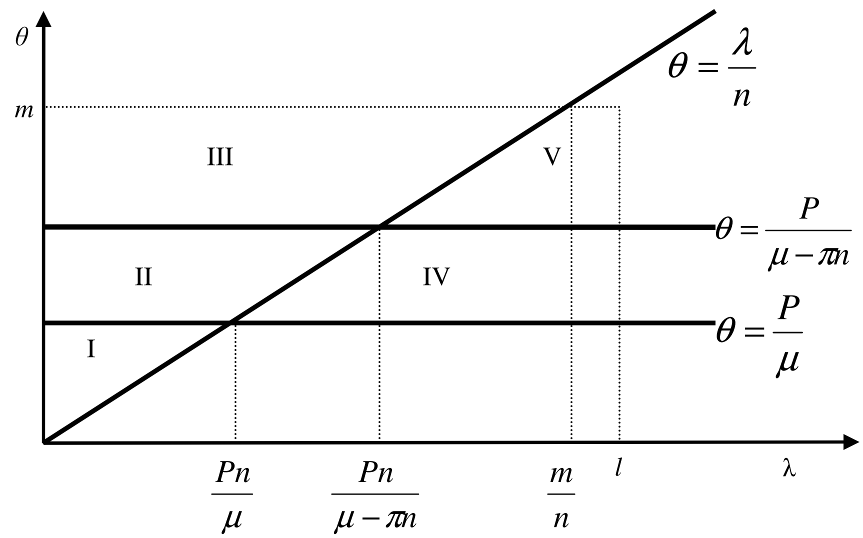
Alternatively, when sorting is prohibited through bundling, buyers in regions I, II, III, and V purchase the product

Figure (1)



If quality is distributed uniform between *(μ-n)* and *(μ+n)* as was previously assumed, then Δq^e is *n* and q_n^e is *μ-πn*. Figure (1) can then be represented as below in Figure (2).

Figure (2)



So far, π, the proportion of consumers sorting goods, has been considered exogenous. In fact, this variable can be specified as the ratio of consumers in regions I, II, and III, the sorters, to those in regions I, II, III, and V. So, the proportion of sorters can be specified as:

$$\pi = \frac{\int_0^m \int_0^{(\theta \Delta q^e)} f(\theta, \lambda) d\lambda d\theta}{\int_0^m \int_0^{(\theta \Delta q^e)} f(\theta, \lambda) d\lambda d\theta + \int_{P/\mu}^{P/q_n^e} \int_{(\theta \Delta q^e)}^{l} f(\theta, \lambda) d\lambda d\theta} = \frac{\text{Regions I, II, and III}}{\text{Regions I, II, III and V}} \qquad (16)$$

Even under fairly simply parameterizations of *f(θ,λ)* and *g(q),* obtaining an explicit analytic specification of π is confounded by the fact that expected quality levels are themselves functions of π. For example, in the uniform distribution case stated above, the solution to π is the root of cubic equation which though analytically tractable, is difficult to interpret[4].

[4] See Appendix B for discussion and an overview of the cubic root method.

Even without an explicit solution for π, it is still possible to determine which selling strategy yields higher revenues. Prices under both strategies are equal if the probability masses of regions I and IV are equal. Suppose that P' is the market clearing price when sorting is prohibited. If sorting is suddenly allowed while the price remains unchanged, sellers lose all the buyers in region V while simultaneously gaining all the consumers in region I. If the probability mass of is region I is larger than region IV then more customers are gained by allowing sorting than are lost. This excess demand implies that the market will clear at a higher price when sorting is allowed. Alternatively, if region I is smaller than region IV, then larger numbers of customers are lost when sorting is allowed than are gained. In this case, the market will clear at a lower price when sorting is allowed.

When quality is distributed uniformly distribution, an increase in *n* indicates that quality is more variable. As *n* increases the slope of $\frac{\lambda}{n}$ flattens and the horizontal line $\frac{P}{\mu - \pi n}$ shifts upward. Both these effects make region V smaller relative to region I implying that a larger percentage of consumers will sort when allowed to do so. The intuition for this result is that sorting is a fixed cost, but the returns to sorting increase as quality becomes more variable.

The sorting strategy acts as a quality discrimination mechanism because it assigns higher quality sorted goods to consumers who value quality little (the region I consumers) while assigning higher quality goods to consumers who value them more (the region V consumers). The seller can only accomplish price discrimination by exploiting the fact that buyers in region I have a low cost to sorting. Because these consumers sort goods, they get a good of higher than average quality. If selling were prohibited, they would not purchase a good of only average quality. By sorting, however, they truncate the quality distribution offered to buyers not sorting. In the absence of a price change, under sorting, consumers in regions IV and V are worse off, consumers in regions I are better off, and consumers in regions II and III face ambiguous changes in welfare. Buyers in regions IV and V, who have a strong preference for quality and high cost of sorting, prefer sellers to prohibit sorting. Alternatively, buyers in region I who have weak preferences for quality and low cost of sorting prefer to be allowed to sort goods.

Even though this example shows that sorting may increase seller revenue, it reduces the consumer surplus for three reasons. First, sorting diverts goods from to consumers in region I who have weak values of quality from consumers in region IV who have strong values of quality. Second, similarly, sorting diverts higher quality goods to consumers in region I from consumers in region V who value the added quality more. Third, sorting in itself is costly and the total benefits to consumers are necessarily reduced by the sum of the sorting costs.

III.E The Free Disposal Equilibrium

So far, it has been assumed that goods are priced so that all goods sell. This market clearing condition is unrealistic when goods are extremely variable in quality. Sellers may attempt to identify quality differences to charge separate price for goods. If this is not feasible, however, sellers may opt not to clear the market. Instead, sellers discard a portion of their goods once they have been picked through. If all consumers sort goods, discarded goods are the lowest quality in the distribution. If sellers can pre-commit to certain level of disposal they can raise their average product quality even if they sellers themselves cannot identify quality characteristics. This section finds conditions where it is profitable for consumers to throw out goods in a comparative static framework.

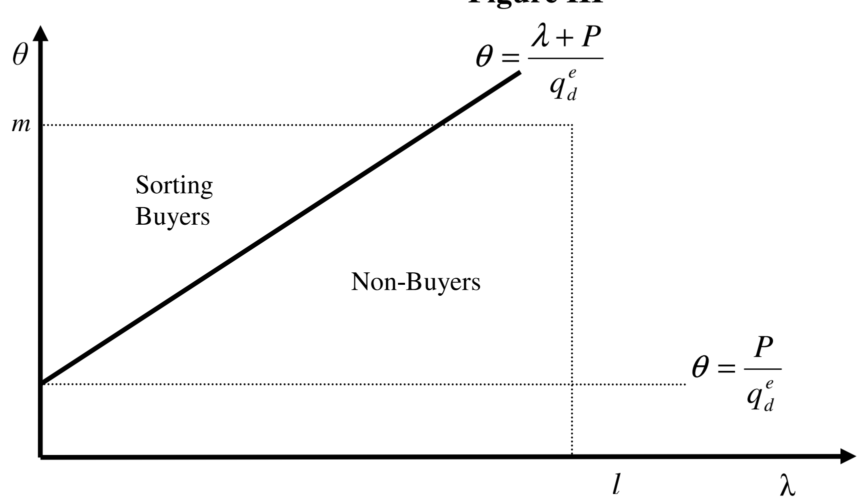
When all consumers sort goods, the incentive compatibility constraint is not longer relevant since the non-sorting option no longer applies. Instead, the individual rationality (IR) constraint binds and is represented as:

$$\theta q_d^e - \lambda - P \geq 0 \tag{17}$$

$$\theta \geq (\lambda + P)/q_d^e \tag{18}$$

The Figure (3) below shows the regions of the *f(θ,λ)* distribution that correspond to whether consumers purchase goods. Let δ be the percentage of goods sold and 1- δ is the percentage of goods thrown out and, again, assume that quality is uniformly distributed in the range $(\mu + n, \mu - n)$. The expected quality of goods sold in the disposal system, q_d^e, is equal to $\mu + (1-\delta)n$. As disposal increases, δ falls and q_d^e increases. Because disposal raises the expected quality, q_d^e is greater than the average quality with no disposal.

Figure III



With disposal, sellers maximize the following profit function:

$$\Pi = (\delta P - c) \times N \tag{19}$$

The variable *c* represents wholesale costs. Once again assuming that quality preference and sorting costs are distributed uniformly, profits represents in equation (19) are maximized subject to the restraint that portion of supply sold equals demand as follows:

$$\delta N = \frac{Mq_d}{2ml}\left(m - \frac{P}{q}\right)^2 \tag{20}$$

Making price a function of quantity in equation (20) and combining it with equation (19) yields:

$$P = q_d m - \sqrt{\frac{2ml\delta N q_d}{M}} \tag{21}$$

Reinserting prices in the profit allows one to solve for the *N* and *δ* by solving the first order conditions below:

$$\frac{\partial \Pi(N,\delta)}{\partial N} = \delta P - c + N\delta \frac{\partial P}{\partial N} = 0 \tag{22}$$

$$\frac{\partial \Pi(N,\delta)}{\partial N} = \delta\left(q_d m - \sqrt{\frac{2ml\delta N q_d}{M}}\right) - c + \delta N\left(-\sqrt{\frac{\delta ml q_d}{2NM}}\right) = 0 \tag{23}$$

$$N^D = \frac{2M}{9\delta q_d ml}\left(q_d m - \frac{c}{\delta}\right)^2 \tag{24}$$

Substituting N^D back into the equation (21) yields:

$$P^D = q_d m - \sqrt{\frac{2ml\delta q_d}{M}}\sqrt{\frac{2M}{9ml\delta q_d}\left(q_d m - \frac{c}{\delta}\right)^2} \tag{25}$$

$$P^D = q_d m - \frac{2}{3}q_d m + \frac{2}{3}\frac{c}{\delta} = \frac{1}{3}q_d m + \frac{2}{3}\frac{c}{\delta} \tag{26}$$

Substituting P^D and N^D into the profit equation yields the following:

$$\Pi^D = \left(\delta\left(\frac{1}{3}q_d m + \frac{2}{3}\frac{c}{\delta}\right) - c\right)\frac{2M}{9ml\delta q_d}\left(q_d m - \frac{c}{\delta}\right)^2 \tag{27}$$

$$\Pi^D = \frac{2M}{27mlq_d}\left(q_d m - \frac{c}{\delta}\right)^3 \tag{28}$$

The following discussion shows the some disposal increases profits as long the marginal effect of a change in disposal, δ, on profits, Π, is negative when there is no disposal. In terms of equation (28) disposal increases revenue if $\frac{\partial \Pi}{\partial \delta} < 0$ when $\delta = 1$. Let $q_d' = \frac{\partial q_d}{\partial \delta}$ represent the marginal effect of a change in disposal on quality. The change in profits from a small change in disposal is:

$$\frac{\partial \Pi^D}{\partial \delta} = c\frac{q_d'}{q_d} + 2q_d' m + 3c \le 0 \tag{29}$$

If the derivative in equation (29) is negative when evaluated at δ equals 1, then allowing some disposal is profitable. This inequality can be considered in its relationship to wholesale costs, *c*, as:

$$c \le 2q_d' q_d m\left(q_d' + 3q_d\right)^{-1} \tag{30}$$

Unsurprisingly, disposal is more likely to occur when wholesale costs are lower. Moreover, as the marginal effect of disposal on quality increases, sellers are more likely to use disposal to improve quality. Additionally, as *m* increases, the profitability of disposal increases in the neighborhood of *δ* equaling one. Since *m* can be interpreted as the range of consumer preferences for quality, this suggests that disposal is more profitable as consumer preferences become more heterogeneous.

The optimal level of disposal is the solution to the first order conditions of the profit function as expressed in equation (31):

$$\delta^{D} = \frac{c}{2qm} \pm \frac{1}{q'}\sqrt{\frac{c^{2}q'^{2}}{4q^{2}m^{2}} - \frac{6q'c}{m}} \qquad (31)$$

The variable q_d and q'_d are themselves functions of δ^{D} making this an imperfect solution for analytic purposes. Again, assuming a uniform distribution, this yields the following first order condition in equation (32)[5].

$$\frac{\partial \Pi}{\partial \delta} = -cn\delta - 2nm\delta^{2}\left(\mu + (1-\delta)n\right) + 3c\left(\mu + (1-\delta)n\right) = 0 \qquad (32)$$

$$2nm\delta^{3} - (2n^{2}m + 2nm\mu)\delta^{2} - 4c\delta n + 3c\mu + 3cn = 0 \qquad (33)$$

Unfortunately, like the solution to the sorting equilibrium, the optimal level of disposal is the root of a cubic equation and therefore difficult to interpret analytically.[6] So while equation (30) demonstrates conditions in which *some* disposal is profitable, determining the actual level of disposal the firms set in an analytical framework is unclear.

Alternatively, the optimal level of disposal can be represented in terms of the elasticity of quantity demanded with respect to disposal rates, $\varepsilon_{N,\delta}$, and elasticity of price with respect to disposal rates, $\varepsilon_{P,\delta}$[7].

$$\frac{\partial \Pi}{\partial \delta} = (\delta P - c)\frac{\partial N}{\partial \delta}\frac{\delta}{N} + \left(1 + \frac{\delta}{P}\frac{\partial P}{\partial \delta}\right)\delta P = 0 \qquad (34)$$

$$\delta^{D} = \frac{c}{P}\frac{\varepsilon_{N,\delta}}{\left(\varepsilon_{N,\delta} + \varepsilon_{P,\delta} + 1\right)} \qquad (35)$$

5 See Appendix C for the exact derivation of equation (32)
6 See Appendix B for details of the difficulties analyzing cubic roots of δ
7 See Appendix D for the exact derivation of equation (35)

Both $\varepsilon_{N,\delta}$ and $\varepsilon_{P,\delta}$ are negative. Notice that as the price-cost ratio increases, ($\frac{c}{P}$ approaches zero), disposal increases (δ^D approaches zero). When markups over wholesale prices are high, small percentage changes in price due to changes in the amount of disposal are relatively large. Also, notice that as the elasticity of price with respect to change in disposal increases ($\varepsilon_{P,\delta}$ approaches negative infinity), the level of disposal increases (δ^D approaches zero).

This analysis offers some insight into the extent to which retailer disposal raises wholesale demand. The magnitude of a change in the amount of disposal can be recovered from the second order condition in equation (39). If $\frac{\partial N}{\partial \delta}$ is negative, then increased disposal (δ decreases) increases wholesale demand at the margin. If $\frac{\partial N}{\partial \delta}$ is positive, then increased disposal (δ decreases) decreases wholesale demand at the margin.

$$\Pi_N = 0 \rightarrow \delta\left(P + N\frac{\partial P}{\partial N}\right) = 0 \tag{37}$$

$$\Pi_{NN}dN + \Pi_{N\delta}d\delta = 0 \tag{38}$$

$$\frac{dN}{d\delta} = -\frac{\Pi_{N\delta}}{\Pi_{NN}} = -\frac{P + (N+\delta)\frac{\partial P}{\partial N} + \delta\left(\frac{\partial P}{\partial \delta} + N\frac{\partial^2 P}{(\partial N)^2}\right)}{2\delta\frac{\partial P}{\partial N} + N\delta\frac{\partial^2 P}{(\partial N)^2}} \tag{39}$$

Unfortunately, the result is ambiguous. The terms Π_N, Π_{NN}, and $\Pi_{N\delta}$ represent the first and second derivative of the profit function respectively. The term $\frac{\partial P}{\partial N}$ is negative as a consequence of demand sloping down. The term $\frac{\partial P}{\partial \delta}$ is also negative because as disposal falls (δ *increases*) quality also falls and retailers must cut prices. The term $\frac{\partial^2 P}{(\partial N)^2}$ depends on the specific shape of the demand curve which, in turn, depends on the shape of the distribution of θ. It is very easy to construct logical demand functions in which the second derivative is either positive or negative.

One would expect that $\frac{\partial N}{\partial \delta}$ is negative *a priori*, suggesting that both the numerator and the denominator of the right side of equation (39) are negative. Since P is positive, a higher price dampens the responsiveness of wholesale demand to changes in disposal. In other words, higher priced goods are unlikely to see large increases in price as a result of the tendency of retailers to use disposal to raise quality.

IV Extensions and Conclusion

This paper demonstrates that when information is asymmetric and the cost of sorting goods across consumers varies, bundling may be used to quality discriminate. Unlike price discrimination, quality discrimination reduces the consumer surplus relative to the typical case in which quality is assigned randomly by bundling goods or otherwise prohibiting sorting. The inability of sellers to identify quality differences prevents them from charging higher prices for goods of higher quality. When consumers with weak preferences for quality have low sorting costs, then sellers can use this to assign assigning low qualities to higher value consumers even though they cannot identify the consumer's type themselves.

Because quality discrimination is reduces the surplus to trade, buyers and sellers have a strong incentive alternative market mechanisms to distribute goods of varying quality. For instance, sellers may charge consumers for the right to sort goods, as is the case in pick your own strawberry field. Whether charging consumers to sort goods can improve the seller revenue is uncertain, but if consumers with low sorting costs have weak preferences for quality, it is likely a similarly inefficient allocation of quality will result.

The feasibility of using sorting to quality discriminate depends on the joint distribution of sorting costs and preferences across consumers. The strategy is more likely to be adopted when weak preferences for quality are correlated with low sorting costs across consumers. For example, older shoppers with limited incomes and low sorting cost will receive better goods. The strategy is also more likely if strong values of quality are correlated with high search costs. For example, young single shoppers with strong preferences for quality and high sorting costs will receive lower quality goods.

This paper predicts several conditions where disposal is used by producers to improve the expected quality of goods. First, retailers are more likely to use disposal to improve the quality of goods with low wholesale costs than of those with high wholesale costs. Second, retailers are more likely to use disposal when a small increase in disposal greatly increases the expected quality of a good. In this setting, disposal is more profitable when the quality distribution in skewed to the left. Third, disposal is more likely to be used when there is a larger variance in consumer types. Typically, the strength of demand characteristic, θ, is interpreted as income implying that a higher income is associated with a stronger preference for quality. Thus, as the range of incomes rises, m increases, and sellers are more likely to use disposal to increase quality. This agrees with the casual observation that stores with wealthier shoppers are more likely to allow consumer sorting and to discard larger portions of their wholesale purchases. Furthermore, prices are higher in grocery stores with wealthier shoppers than in other the typical grocery store. This paper argues that this phenomenon may represent improved quality control occurring through disposal.

Admittedly, however, it is difficult to distinguish whether this phenomenon is the result of retailers using disposal to improve quality or retailers disposing of goods that have perished through normal decay. It is argued that distinction is unimportant if sellers cannot sort goods once they have been displayed. However, if decay does not presume asymmetric information as sorting does, then sellers and buyers could be equally capable of identifying lower quality goods.

While disposal might initially be considered waste from the standpoint of goods going unused, this paper shows that disposal may be viewed as a quality improvement mechanism and that disposal might be planned by retailers. It is possible the alternative quality improvement mechanisms such as contracting on production processes and genetic engineering may replace disposal as a quality improvement mechanism. In this case, wholesale demand may actually fall as less produce is discarded.

V Bibliography

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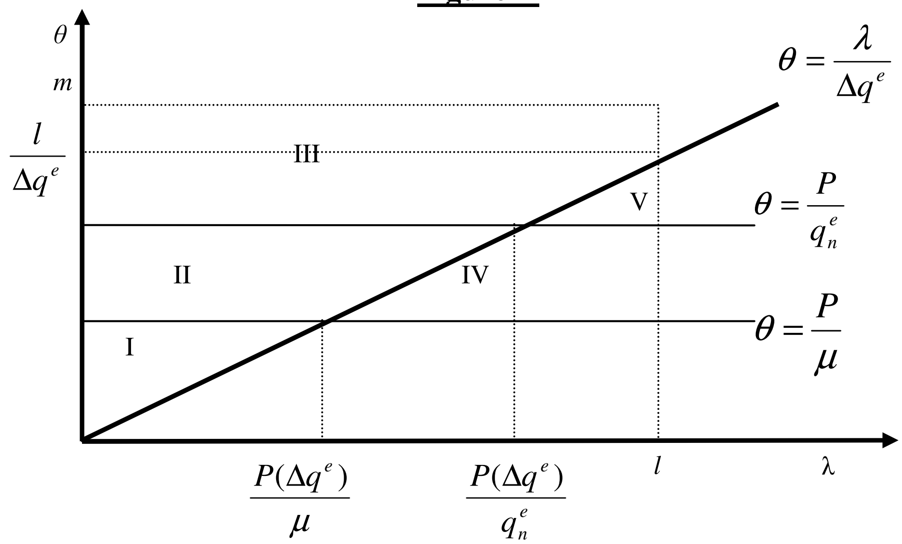
Appendix A -The case where l is less than Δq^e

If l is less than $\frac{m}{\Delta q^e}$,Figure (1) is now represented by Figure (A)

Figure A



Appendix B - Cubic Roots and solving for π and δ

This discussion is drawn from Weisstein (1999). The solutions to π and δ in equations (16) and (33) both require solving a cubic equation. Unfortunately this method yield analytic results that are very difficult to interpret. A summary of the method of finding cubic roots is shown for the following equation

$$z^3 + a_2 z^2 + a_1 z^1 + a_0 = 0 \qquad \text{(B1)}$$

Substituting $z = x - \frac{1}{3}a_2$ convert equation (B1) to:

$$x^3 + \left(a_2 + \tfrac{1}{3}a_1^{\,2}\right)x^1 - \left(\tfrac{1}{3}a_1 a_2 - \tfrac{2}{27}(a_2)^3 - a_0\right) = 0 \qquad \text{(B2)}$$

Setting $p = a_2 + \frac{1}{3}a_1^{\,2}$ and $q = \frac{1}{3}a_1 a_2 - \frac{2}{27}(a_2)^3 - a_0$ yields

$$x^3 + px^1 = q \qquad \text{(B3)}$$

Substituting $x = w - \frac{p}{3w}$ converts equation (B3) into

$$\left(w^3\right)^2 - q\left(w^3\right) + \tfrac{1}{27}p^3 = 0 \quad \text{(B4)}$$

Using the quadratic equation w^3 can be solved for as:

$$w^3 = \tfrac{1}{2}\left(q \pm \sqrt{q^2 - \tfrac{4}{27}p^3}\right) \quad \text{(B5)}$$

The solution to the cubic roots for δ can be recovered by substituting back into the equation below.

$$w = \sqrt[3]{\tfrac{1}{2}\left(q \pm \sqrt{q^2 - \tfrac{4}{27}p^3}\right)} \quad \text{(B6)}$$

<u>Appendix C - Derivation of Equation (32)</u>

$$\frac{\partial \Pi}{\partial \delta} = -cn\delta - 2nm\delta^2\left(\mu + (1-\delta)n\right) + 3c\left(\mu + (1-\delta)n\right) = 0 \quad \text{(C1)}$$

$$-cn\delta + 2nm\delta^3 - 2n^2m\delta^2 - 2nm\mu\delta^2 + 3c\mu + 3cn - 3c\delta n = 0 \quad \text{(C2)}$$

$$2nm\delta^3 - (2n^2m + 2nm\mu)\delta^2 - 4c\delta n + 3c\mu + 3cn = 0 \quad \text{(C3)}$$

<u>Appendix D – Derivative of Equation (35)</u>

$$\frac{\partial \Pi}{\partial \delta} = (\delta P - c)\frac{\partial N}{\partial \delta} + \left(P + \delta\frac{\partial P}{\partial \delta}\right)N = 0 \quad \text{(D4)}$$

$$\frac{\partial \Pi}{\partial \delta} = (\delta P - c)\frac{\partial N}{\partial \delta}\frac{\delta}{N} + \left(1 + \frac{\delta}{P}\frac{\partial P}{\partial \delta}\right)\delta P = 0 \quad \text{(D5)}$$

$$\frac{\partial \Pi}{\partial \delta} = (\delta P - c)\varepsilon_{N,\delta} + \left(1 + \varepsilon_{P,\delta}\right)\delta P = 0 \quad \text{(D6)}$$

$$\frac{\partial \Pi}{\partial \delta} = \delta P\left(1 + \varepsilon_{N,\delta} + \varepsilon_{P,\delta}\right) = c\varepsilon_{N,\delta} \quad \text{(D7)}$$

$$\delta = \frac{c}{P}\frac{\varepsilon_{N,\delta}}{\left(1 + \varepsilon_{N,\delta} + \varepsilon_{P,\delta}\right)} \quad \text{(D8)}$$