Some Economics of Product Line Management

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ABSTRACT: This paper shows that a durable good monopolist may solve the Coase time inconsistency problem by extending a product line over time. With a product line, the firm fragments its high market segment in sub segments that it serves sequentially. Doing so allows the firm to credibly commit to delay sales to the low market segment. The commitment mechanism by which a product line allows the firm to delay sales is that it takes time to develop, promote and distribute new products variants. The product line solution to the time inconsistency problem yields implications on the how prices and quantities vary over time that are broadly consistent with the marketing paradigm of product life cycle. The product line widens as subgroups are targeted with slightly differentiated products customized to satisfy their specific needs. Then, toward the end of the product life cycle, the product is discounted to the low market segment.

[1]The latest version of this paper is available at http://bonvent.upf.es/~courty/my-public-files/wkpp.html. Comments welcome at Pascal Courty, Department of Economics and Business, University Pompeu Fabra, Ramon Fargas 25-27, 08005 Barcelona, Spain or by email at courty@upf.es.

[2]I would like to thank Li, Hao. All errors are my responsibility.

1 Introduction

Product lines are typically narrow early in the product life cycle but they tend to widen over time. Indeed, manufacturers often add product variants by changing the color, design, options, style, motif and layout of their basic product (Shugan, 1989). They typically target consumer subgroups with new products customized to satisfy specific needs. This practice is most visible in many consumer durable goods markets such as the markets for consumer appliances and consumer electronics. For example, Sony added to its basic walkman model an ultra-light model that attaches to sweatband for sport purpose, a solar powered walkman, and also a waterproof walkman (Cooper, 1994). This practice of adding more items within the current range of a product line is known among marketing professionals as 'filling' the product line.

Product line filling should be distinguished from technology-driven product innovations. Obviously, technology-driven innovations explain some product line transformations and possibly some product line extensions. New products may drive obsolete ones out of the product line as consumers replace their older versions with upgraded ones. Technological innovations, however, do not explain all changes in product lines. Firms often extend their product lines by introducing new products that do not overlap the range of existing versions. Rather, these new slightly differentiated products are targeted to satisfy new needs. The observation that firms try to sell their products to as many consumers as possible is simple enough that it does not need elaboration. The question, then, is not so much why firms try to capture new market segments but why they do so sequentially. Why do firms fill their product lines over time? How often should firms add new products? How many products should a firm add to its line over time?

Broadly speaking, these questions mix the static problem of pricing multiple products at a given point in time and the dynamic problem of introducing new products over time to maximize inter-temporal revenues. These issues have not received much attention in the economic literature. Following the early work of Mussa and Rosen (1978), economists have studied the concept of product line mostly from a static point of view.[1] These questions have not received much attention in the marketing literature either. In fact, in his 1993 survey Rao concludes that "The (marketing) literature is not well developed for the case of dynamic pricing models for multiple products."

This work suggests an important reason for why manufacturers of durable goods may extend their product line by slowly adding over time slightly differentiated product. Before explaining the role of product line extensions, it will probably help to briefly review the fundamental challenge of the durable good manufacturer. A durable good manufacturer faces a time inconsistency problem. To understand this point, consider the analysis of Coase (1972). Coase analyzes a durable good monopolist that sells output in several periods. For simplicity, let's assume that the market is composed of only two segments, the high and the low valuation segments. The monopolist faces a time inconsistency problem when it is more profitable to sell only to the high segment. Indeed, the firm is

[1] For an extension of the Mussa and Rosen price discrimination framework to two periods see Fudenberg and Tirole (1996). This works, however, has nothing to say about the timing of product introduction. For other economic theories of product variety that do not focus on price discrimination see the survey by Lancaster (1990).

not able to do so because it cannot resist the temptation to supply—at lower price—the low segment after it has supplied the high one. Because high valuation buyers anticipate a decline in price, they update downward the amount they are willing to pay early. As a consequence, the firm's revenues decline bellow what they would have been had the firm been able to commit to never sell to the low segment. This is called the time inconsistency problem because the firm's interests before and after it has served the high segment are in conflict. Coase brought this argument to its logical end and conjectured that a monopolist may loose all market power.

A product line may help the firm to solve the time inconsistency problem. With a product line, the firm does not serve all high valuation consumers at once. The key idea is that by developing a product line over time, the firm fragments the high valuation segment in sub-segments that it sequentially serves. The mechanism by which a product line allows the firm to delay sales to the low segment is that it takes time to bring new products to the market. The delay between two product introductions is entirely exogenous to the model. It may be due to technological constraints on research and development or to marketing constraints associated with new product introduction, promotion, and distribution. Because of these constraints, consumers do not anticipate new products to reach the markets in "the twinkling of an eye" in the same way they anticipated prices to drop in the Coase conjecture. The firm always keeps a market of attractive high valuation consumers to sell to so that it has less incentive to move down its demand curve. The product line, then, effectively allows the firm to commit to keep prices high in a way that is time consistent.

There are other schemes, in addition to the product line approach, that have been proposed to solve the time inconsistency problem. I contrast the product line solution with the standard textbook solution. Bullow (1982) suggested that a durable good manufacturer might be able to avoid the time inconsistency problem by renting rather than selling its product. His argument is consistent with the observation that some producers of industrial goods such as Xerox for copy machines and IBM for mainframe computers only lease their products. This leasing solution, however, is rarely observed for the consumer durable goods such as walkman and digital cameras I have in mind in the context of product line management. (This could be, among other reasons, because of the mass-market characteristic of some of these goods and also because of potential moral hazard problems.) In these markets, the firm typically sells the good to consumers. When leasing is excluded, this paper has shown that the firm can still solve the time inconsistency problem by filling a product line over time. Contrasting the leasing and the product line solutions suggests that those firms that do not lease their products will be more likely to introduce new products over time and to have longer product lines.

This paper also contributes to the marketing literature. One of the reasons found in the marketing literature for manufacturers offering a product line is heterogeneous consumer tastes. The literature use the term *product assortment* to describe the variations in the line at the retailer level and claims that product assortment is a way for retailers to reach different market segments (Kotler, 1997). Although this interpretation do explains why retailers offer product lines, it does not have much to say about the dynamic dimension of product line management. The model presented here goes one step further and suggests that firms may deliberately sequentially serves their markets. Moreover, this

work demonstrates how the market will be split in different segments of different sizes and how the timing between two product introductions depends on the firm's incentive to compete with itself in the future.

As a final contribution, this work also hints at a possible theory of product life cycle that is consistent with the standard marketing textbook (Kotler, 1997). Briefly summarized, the model predicts the following stages in the product life cycle. At the beginning of the product life cycle, the firm offers few products that are targeted exclusively to the high segment. At this early stage, sales volume and prices are high. Then, as the product moves along its life cycle, the product line widens as subgroups with specific needs are targeted. Finally, during the decline phase of the life cycle, margins go down as the product is discounted to the price sensitive segment.

The paper is organized as follow. The next section describes the model. Section three presents the main intuition of the model for the two-products line case. Section four goes trough a more complete analysis on the timing of new product introductions and on the optimal product line length. Section five contrasts the product line solution with the time inconsistency literature and outlines additional predictions regarding the product life cycle. Section six summarizes the main results and concludes.

2 The Model

A simple model with two types of buyers and an infinite horizon will suffice to capture the main insights of the time inconsistency problem. Assume a unit continuum market of non-atomic consumers. Fraction π_h of consumers have high valuation and fraction $1-\pi_h$ have low valuations.[2] High and low valuation consumers value an undifferentiated version of the product v_h and $v_l < v_h$ per period. The ratio v_h/v_l will be interpreted as a measure of the price premium that the high segment is willing to pay relative to the low one. Both the firm and the consumers live forever and have a discount factor β. To focus on the main issues, production costs for the undifferentiated product will be assumed to be zero.

Consumers are willing to pay for the undifferentiated product at the beginning of any period, $\frac{v_t}{1-\beta}$, $t = l, h$. When the monopolist can commit to sell only to the high segment, its profits are

$$\Pi^m = \frac{\pi_h v_h}{1-\beta}.$$

Under no-commitment, the monopolist sells the good in period one at $p_1 = v_h + \beta\frac{v_l}{1-\beta}$ to the high segment and in period two at $p_2 = \frac{v_l}{1-\beta}$ to the low segment. The Coase profits are,

$$\Pi^c = \pi_h v_h + \beta\frac{v_l}{1-\beta}.$$

To capture the essence of the Coase time inconsistency problem, I assume that the monopolist prefers to sell to the high segment only,

$$\pi_h \frac{v_h}{v_l} > 1.$$

[2] By assuming a continuum of high and low valuation buyers, I rule out the schemes proposed by Bagnoli, Salant and Swierzbinski (1989) to escape the Coase conjecture.

In this situation, the potential gains from solving the time inconsistency problem are, $\Pi^m - \Pi^c = \beta \frac{\pi_h v_h - v_l}{1-\beta}$. As predicted under the Coase time inconsistency problem, these gains are greater when the price premium is greater, when the high segment is larger and when discounting is less important.

The rest of the paper investigates how product lines mitigate the time inconsistency problem. Product lines obviously change many dimensions of the firm's pricing problem. The core of this paper, however, will focus exclusively on two features: (a) Product lines fragment the market into sub-markets of differentiated products that are imperfect substitutes. (b) New products take time to develop so that product lines are typically extended sequentially. I formalize these two features more thoroughly next. A more complete discussion of other features of product lines—they supply diversity, expend markets, and may cannibalize existing segments, to name just a few—is deliberately postponed until Section 5.

I capture the concept of market fragmentation by assuming that each consumer favors only one product in the line. To keep consumer preferences simple, I will assume that consumers value one of the differentiated product highly and all other products less but equally. Given a product line, each consumer value her favored product at $v_t^+ > v_t$ and all the other ones at $v_t^- < v_t^+$, for $t \in (h, l)$. I assume that differentiating a product costs δ_c per unit.

The main intuition of the paper can be more easily presented by restricting to a subset of consumer preferences. In the main core of the paper, I will assume that $v_h^+ = v_h + (1-\beta)\delta_c$, and $v_l^+ = (1-\beta)\delta_c$. This first assumption implies that the net surplus from trade with the high segment is the same under the undifferentiated product and the product line ($\frac{v_h}{1-\beta}$). This allows me to isolate the market fragmentation effect from the market expansion one. The second assumption says that low valuation consumers do not value any differentiated good more than its cost. This guaranties that the firm will never sell a differentiated product to low valuation consumers. The firm may, however, sell them the undifferentiated product so that the Coase time inconsistency problem still prevails. This specification greatly simplifies the analysis without much loss of insight. I will show in the last part of Section 4 that the main results still hold for more general preferences although the analysis is slightly more involved.

The other key feature of the product line is that it imposes a timing of product introduction. The firm commits in the first period on a sequence of product introductions and consumers have rational expectations on the timing of these introductions. The delay between two product introductions could be interpreted as technologically driven due to constraints on research and development or on the production technology. Alternatively, it could be interpreted as marketing-driven due to promotion, logistic and distribution constraints. To start, I will assume that only two new products are introduced and each introduction can be delayed by at most one period. The length of time between any two periods will be interpreted as minimum amount of time necessary to introduce a new product. Then, I will consider the case where the firm can endogenously chose the length of time between any two introductions and can choose the product line length.

3 Two-Products Line

In the two products line case, assume that each consumer likes one product with probability α and the other with probability $1-\alpha$. Let's arbitrarily consider the case where the firm sells the differentiated product with market share $1-\alpha$ in the first period, then sells in the second period the differentiated product with market share α, and finally sells the undifferentiated product in the third period. Under this scenario, high valuation consumers anticipate that in period three, after all high valuation consumers have bought, undifferentiated products will sell at

$$p_3 = \frac{v_l}{1-\beta}.$$

Consider now the following equilibrium where fraction α of the high segment buy in period two at,

$$p_2 = v_h + \beta\frac{v_l}{1-\beta} + \delta_c,$$

and fraction $1-\alpha$ of the high segment buy in period one at,

$$p_1 = v_h + \beta v_h + \beta^2\frac{v_l}{1-\beta} + \delta_c.$$

Under these prices, high valuation buyers are actually indifferent between buying their favored good in the product line and waiting for the discount sales in period three. In addition, prices p_1, p_2 and p_3 are the highest prices the firm can charge if it sells its product line sequentially. Comparing the product line prices with the Coase prices, one finds that under the product line strategy, prices start at higher levels and decrease for a longer period of time toward the same closing level. The logic for identical closing price is the same as in the Coase problem: the monopolist cannot commit not to sell to the low segment of the market. The difference now is that the firm can delay the date on which it will discount the product to the low types.

The profits under the product-line pricing strategy are,

$$\Pi^2 = \pi_h((1-\alpha)(p_1-\delta_c) + \beta\alpha(p_2-\delta_c)) + \beta^2(1-\pi_h)p_3.$$

The producer chooses to sequentially sell a product line if these profits are greater than the Coase profits,

$$\Pi^2 > \Pi^c.$$

After simplifications, this condition is equivalent to

$$\beta\pi_h v_h > \alpha\pi_h v_h + \beta v_l,$$

where the term on the left hand side represents the gains earned in the second period from delaying sales to the low segment by one period. The first term on the right hand side represents the forgone sales to fraction α of the high segment in the first period while the second term represents the forgone sale to the low segment in the second period. Written differently,

$$\pi_h\frac{v_h}{v_l} > \frac{\beta}{\beta-\alpha}$$

this condition implies that the firm prefers to sell a product line when the price premium v_h/v_l is large, when the fraction of the high segment π_h is large, when the fraction of consumer served first $1-\alpha$ is large, and when the discount factor β is large.

Selling a product line does not completely solve the firm's time inconsistency problem. Indeed, it raises a new type of time inconsistency. In the second period, the firm may prefer to sell to both fraction α high segment and to the low segment than selling first at a high price to the leftover high segment and then, in the following period, at the low price to the low segment. The intuition for this new source of time inconsistency is that the firm is facing in the second period a smaller high market segment. Subgame perfection in the second period requires that the continuing profits are greater than the profits from liquidating the market at a low price,

$$\alpha\pi_h v_h > (\alpha\pi_h + (1-\pi_h))v_l.$$

This condition is more likely to hold when the price premium v_h/v_l is large, when the fraction of high type π_h is large, and when the fraction of consumers served first $1-\alpha$ is low.[3]

To complete the analysis, one must compare profits under the two-products line strategy with the Coase profits. This comparison will determine the decision to market a product line. I first consider the case where the market share of each product is exogenously given. Then, I consider the case where the firm can design the two products so that it can arbitrarily endogenously choose α.

Exogenous Market Segmentation. The firm chooses the sequence of product introduction that maximizes profits subject to the second period time consistency constraint. The firm faces a dilemma because profit maximization and time consistency may conflict. It would like to sell the product with the largest share first but this may lower the chances that the second period time consistency constraint holds. Assuming arbitrarily that $1-\alpha > 1/2$, the analysis suggests that the firm will sell a product line under two situations.

1. When $\pi_h v_h/v_l > Max(\frac{1-\pi_h}{\alpha}+\pi_h, \frac{\beta}{\beta-\alpha})$, the firm sells in the first period the differentiated product with a largest market share, in the second period the differentiated product with a smallest market share and in the third period the undifferentiated product.

2. When the above condition does not hold but $\pi_h v_h/v_l > Max(\frac{1-\pi_h}{1-\alpha}+\pi_h, \frac{\beta}{\alpha+\beta-1})$ the firm sells in the first period the differentiated product with the smallest market share, in the second period the differentiated product with the largest market share and in the last period the undifferentiated product.

[3]This behavior is not the only type of time inconsistent behavior that may tempt the firm in period two. The firm may also choose to sell the first period product to the low valuation consumers in addition to the second period product to the high valuation consumers. Given the consumer preferences under consideration, however, this deviation does not increase profits because low valuation consumers have zero net valuation for their favored product in the product line. This second kind of deviation may matter under more general consumer preferences. I will show in the extension Section, that taking this into account does not change very much the predictions.

The first condition holds when the largest market share is large, so that there are some gains from delaying sales, but not too large so that the firm can still commit to postpone selling the undifferentiated product until the third period. The second condition holds when selling the product with the largest market share first violates the second period time consistency constraint. The problem is time consistent, however, when the firm starts by selling the product with small market share first.

When none of the above two conditions hold, the firm prefers selling the undifferentiated product than the product line. The firm does not offer a product line either because it is not profitable or because it is not time consistent to do so. What is most surprising is that the product line is more likely to solve the time inconsistency problem when this problem is most acute, that is, when π_h is close to one or when v_h/v_l is large. Therefore, the product line solution is more likely to be used when the Coase time inconsistency problem causes the most damages. This shows that a product line is a robust solution to the time inconsistency problem.

The analysis suggests that the firm always starts selling the product with largest market share when the time inconsistency problem is salient (π_h high and/or v_h/v_l high). The intuition is that when the time inconsistency problem is salient, the second period time consistency constraint holds so that the firm will can capture the largest market share of its high segment early on. This result can be generalized to the case where the two products can fetch different values say v_h and v_h' from the high segment consumers. Assume arbitrarily that product v_h controls a market share α while product v_h' controls market share $1-\alpha$. Assume also that the time inconsistency problem is salient so that the second period time consistency condition holds. One can show that the firm sells first the product with largest market value

$$Max(\alpha v_h, (1-\alpha)v_h').$$

The intuition again, is that the firm wants to sell to as many high types as possible in the first period to minimize the loss of forgone sales.

Endogenous Market Segmentation. So far, it was assumed that the monopolist took as given the market share of each product in the line. In practice, however, the firm can design the product line in a way that it actually chooses the fraction of consumers who prefer each product. For example, Sony split its market between sport users (ultra-light model with sweat strap band), outdoor users (water-resistant model) and environmentally concerned users (solar powered). To capture this feature, assume that the producer can choose the market share of high valuation buyers that will buy in the first period. Because profits increase as more consumers purchase in the first period, the firm chooses the first period market share that binds the second period time consistency condition,

$$\alpha^* = \frac{v_l}{v_h - v_l}\frac{1-\pi_h}{\pi_h}.$$

Substituting the optimal market share in the firm's profits gives,

$$\Pi^2 = \pi_h v_h(1+\beta - \frac{1-\pi_h}{\pi_h}\frac{v_l}{v_h - v_l}) + \frac{\beta^2}{1-\beta}v_l.$$

This expression shows that the product line solves completely the time inconsistency problem in the second period as the fraction of high types increases to one or as the price premium increases to infinity. In these situations, the fraction of early buyers converge to one and the firm captures all the second period monopoly profits.

The Coase profits and the profits under the product line strategy both increase as the discount factor increases. The product line profits, however, increase more than the Coase profits as the discount factor increases. The intuition is that the second period gains from selling to the high segment are weighted by the discount factor. An increase in the discount factor increases the value of these second period gains. This implies that product lines are relatively more profitable when discounting is less important. Actually, one can refine this claim by distinguishing firm discounting and consumer discounting: When the firm discounts less, it is more likely to use choose the product line strategy. This implies that well-established firms which do not need fast-cash are more likely to use product lines.

4 More Complete Analysis

This section extends the model in three directions. First, I consider the case where the firm can endogenously choose the pace of new product introductions. Second, I consider the case where the firm can introduce more than one new product in the line. Finally, I extend the model to more general consumer preferences. The important results of these extensions are summarized at the end of the section.

Optimal Timing of Product Introduction. The product line allows the firm to delay the date on which the undifferentiated product will be discounted to the low segment. This, in turn, increases the willingness to pay of early buyers. So far, the waiting spell between two product introductions was assumed to be constant. The firm, however, could control the introduction date of the second product by specifying that product in a way that it requires longer to develop. Would the firm choose to do so? Consider for example the case where the firm has a product line which meets the second period time consistency constraint and can choose a product design that postpones further the introduction date for the second product. The answer is yes—at least as long as the second period time consistency condition still holds after the modification. The intuition is simple. Postponing the introduction of the second product further allows the firm to raise the price that it can charge to the early batch of consumers.

These considerations raises a new set of question which have to do with the optimal timing of product introductions. I now investigate the possibility for the firm to choose the length of time between two product introductions. Assume that the firm can specify the second product so that it endogenously chooses its introduction date. Conforming with the spirit of the Coase conjecture, I assume that the introduction of the undifferentiated product, however, cannot be artificially postponed. The firm sells to fraction $1-\alpha$ of high types in period one, to fraction α of high types in period t, and to the low types in period $t+1$. Because early buyers now have to wait longer to find the product they prefer

at a discounted price, the firm can increase the early price to,

$$p_1 = v_h + \beta v_h + .. + \beta^t v_h + \beta^{t+1}\frac{v_l}{1-\beta} + \delta_c.$$

No trade occur between period 2 and period $t-1$. The prices in period t and $t+1$ are respectively $p^t = v_h + \beta\frac{v_l}{1-\beta} + \delta_c$ and $p_{t+1} = \frac{v_l}{1-\beta}$. Period two time consistency implies time consistency in subsequent periods because the waiting cost decreases as the firm gets closer to the second introduction date. The period two time consistency constraint is now,

$$\beta^{t-1}(\alpha\pi_h v_h + \beta(\alpha\pi_h + (1-\pi_h))\frac{v_l}{1-\beta})) > (\alpha\pi_h + (1-\pi_h))\frac{v_l}{1-\beta}.$$

The right hand side is the same as before because the gains from deviation have not changed. The left-hand side, however, is now delayed by $t-1$ periods and therefore decreases as t increases. Consider first the case where the market shares of the first and second products are fixed, the firm will choose the highest t such that the above inequality holds. As suggested above, delaying the introduction of the second product increases profits. Let $\Pi^{2,t}$ be the profits when two products are introduced, the first in period one and the second in period t. The increment in profits from delaying the second introduction by one more period are positive as long as it is profitable to carry a two-products line,

$$\Pi^{2,t} - \Pi^{2,t-1} = \beta^{t-1}(\Pi^2 - \Pi^c) = \beta^{t-1}(\pi_h v_h(\beta - \alpha) - \beta v_l).$$

In addition, the increment in profits decreases as the second product is introduced later.

Consider now the case where the firm can choose both the market share of the two products in the line and the timing of product introductions. Solving for the optimal market share for the second product when it is introduced in period t gives,

$$\alpha^t = \frac{1-\pi_h}{\pi_h}\frac{v_l}{\frac{v_h}{1+\beta^{-1}+..+\beta^{-(t-1)}} - v_l}.$$

The early market share decreases as t increases because the firm has to wait longer so that it is more tempting to sell the undifferentiated product. Plugging the optimal early market share into the profit function, one can solve for the optimal product introduction date for the second product. Delaying the introduction of the second product has two effects: a positive effect due to the fact that early buyers are willing to pay more because they find waiting more costly and a negative effect because delaying sales imply that the firm must serve a smaller market share early so that it has no incentive to deviate and liquidate the product line at the low price in period two. As a result of this second effect, the firm never delays the introduction of the second product forever because the fraction of the market served early $1-\alpha^t$ converge to zero as the second introduction is delayed forever.

The firm will delay more the introduction of the second product as the high segment is larger (π_h larger) and as the price premium is larger (v_h/v_l higher).[4] In the limit, the profits converge to the monopoly profits as the fraction of the high segment increases to one and/or as the price premium increases to infinity. In these situations, the firm sells to the entire high segment in the first period, delays the sales to the low segment for ever an extracts all surplus from the high segment. The Coase time inconsistency problem is completely resolved!

N-Products Line. The firm may have an incentive to delay sales to low segment by introducing more than two products. For example, the firm could invest in a research and development project and expects to get several new products from this project at different points in time. Assume that the firm can choose both the number of products to sell and the market share of each product. Under this assumption, one can easily show that the firm will optimally choose to introduce one new product every period. In fact, given that the firm can introduce as many products as it wants, there is no point to delay any two introductions by more than one period.

Under n new products introductions, the firm sells differentiated product to the high segment from period one to period n and sells the undifferentiated product to the low segment in period $n+1$. The market closes after period $n+1$. The firm charges in period $m < n+1$,

$$p_m = v_h + \beta v_h + .. + \beta^{n-m} v_h + \beta^{n-m+1} \frac{v_l}{1-\beta} + \delta_c,$$

and $p_{n+1} = \frac{v_l}{1-\beta}$ in the last period. High valuation consumers purchase as soon as their favorite good is introduced while low valuation consumers do not purchase until the last period. As before, prices slowly decrease to the same low level as under the Coase scenario. Now, however, prices start at higher levels and decrease during more periods. A prediction of the model is that prices should be higher at the beginning of the product life cycle and decreases over the life cycle. In addition, prices should decrease over a longer length of time for broader product lines.

Let α_n be the market share of the product sold when there are $n-1$ more products to be introduced. According to this notation, α_1 is the market share of the last product introduced,

$$\alpha_1 = \frac{v_l}{v_h - v_l} \frac{1-\pi_h}{\pi_h}.$$

Notice that α_1 does not depend on the total number of products introduced because the time consistency constraint in the last period does not depend on what has happened before. For the same reason, α_n is also independent of the total number of products introduced.

The market share of the product introduced when one more product will be introduced, α_2, must satisfy the time consistency condition when there are two more periods to go,

$$\pi_h v_h \left(\alpha_2(1+\beta) + \beta\alpha_1\right) > \left((\alpha_1+\alpha_2)\pi_h + (1-\pi_h)\right) v_l(1+\beta).$$

[4]The overall effect of increasing the fraction of the high segment on the first period supply is ambiguous. There are two opposite forces. Keeping the introduction date of the second product constant the first period supply increases. The introduction date, however, will be postponed implying smaller first period supply.

The left hand side represents the gains in the last three periods if the firm introduces the products slowly as predicated by the optimal product introduction strategy while the right hand side represents the gains from deviating and selling the product line to all consumers at the low price. (These gains are net gains after all identical terms have been canceled.) Solving for α_2 gives,

$$\alpha_2 = \frac{v_l}{v_h - v_l}\frac{1}{1+\beta}(\alpha_1 + \frac{1-\pi_h}{\pi_h}).$$

To interpret α_2, assume that there are only 3 product introductions. The market share of the second products introduced decreases with the price premium. The intuition is simple. When the price premium is large, the firm wants to sell as much as possible in the first period, $1-\alpha_1-\alpha_2$, so that the firm will decrease both α_1 and α_2. The market share for the second product introduced is smaller than the market share of the third product introduced ($\alpha_2 < \alpha_1$) if and only if $\frac{v_l}{v_h - v_l} < \beta$. This is also more likely to happen when the price premium is greater.

More generally, solving for the time consistency condition when there are $n-1$ more products to be introduced gives,

$$\alpha_n = \frac{v_l}{v_h - v_l}\frac{1}{1+\beta+..+\beta^{n-1}}\left(\alpha_1 + .. + \alpha_{n-1} + \frac{1-\pi_h}{\pi_h}\right).$$

The firm tries to sell as much as possible to the high segment in the first period, then keep on serving the high segment little by little and finally serves the low segment. The model therefore predicts that quantities should be high at the beginning and at the end of the product life cycle and low in between. The market share of new products will decrease as long as the price premium is not too large, $v_h < 2v_l$. Otherwise, the market share of new products may increase.

The profits under n new product introductions are,

$$\Pi_n = \pi_h v_h \left((1 - \sum_1^n \alpha_i) + \beta((1 - \sum_1^{n-1} \alpha_i) + .. + \beta^{n-2}(1-\alpha_1) + \beta^{n-1}\right) + \beta^n \frac{v_l}{1-\beta}.$$

As before, increasing the number of products has two effects. First, it solves the time consistency problem and allows the firm to extract more surplus from early buyers. Second, however, it delays sales to part of the high segment and to the low segment and therefore reduces total surplus. Overall, the condition for increasing the product line length by one more product when its length is already n is,

$$\beta^n(\pi_h v_h - v_l) > \pi_h v_h(\alpha_n + \beta\alpha_{n-1} + .. + \beta^{n-1}\alpha_1).$$

The left hand side represents the net gains from postponing the sales to the high segment by one more period while the right hand side represents the loss from selling more slowly over time. As the number of products introduced increases, the left hand side decreases while the right hand side is bounded bellow by $\frac{v_l}{v_h - v_l}(1-\beta)(1-\pi_h)v_h$ since the α's are bounded from bellow by $(1-\beta)\frac{v_l}{v_h - v_l}\frac{1-\pi_h}{\pi_h}$. For n large enough, this inequality will be violated and the firm will stop introducing new products.

In the limit, the Coase time inconsistency problem will disappear as the price premium increases to infinity, as the fraction of the high segment increases to one and as the discount factor increases to one. In these situations, the firm sells to most of the high valuation buyers in the first period, serves a small fraction of the high segment in the following periods and postpone as long as possible the period on which it sells to the low segment. In the limit, the firm never serves the low segment and the Coase time inconsistency problem completely disappear.

More General Preferences. Consider the two products line case again but assume now the general consumer preferences described in the model section. Without loss of generality, I consider the same product line strategy as in Section 3. To focus on the main issues, I maintain the assumption that there is no market expansion for both types, that is, $v_t^+ = v_t + (1-\beta)\delta_c$, for $t = h, l$. In the more general consumer preference case, the high valuation consumers who were buying in period two may be better off buying in period one. This will be excluded as long as,

$$\beta(\frac{v_h^+}{1-\beta} - p_2) > \frac{v_h^-}{1-\beta} - p_1.$$

This will hold when $v_h^+ - v_h^-$ is sufficiently large. This will typically be the case when consumers have idiosyncratic preferences so that there exists a product line that fragments the market in distinct segments.

This is not the most important change to the model. The most important change is that firm may be tempted in period two by a new type of deviation.[5] Rather than selling the undifferentiated product to all leftover consumers, the firm may sell the period-two differentiated product to the leftover high segment and the period-one differentiated product to part of the low segment. Under that deviation, the firm sells the period-one differentiated product to the low segment at $p_2^l = \frac{v_l^+}{1-\beta}$. To induce the high segment to buy the period-two differentiated product it must reduce its price to $p_2^h = Min(\frac{v_h^+ + v_l^+ - v_h^-}{1-\beta}, v_h^+ + \beta\frac{v_l^+}{1-\beta})$. The product line strategy is time consistent only if this deviation is not profitable. This adds the constraint that,

$$\alpha\pi_h p_2 + \beta(1-\pi_h)p_3 > \alpha\pi_h p_2^h + (1-\pi_h)(1-\alpha)p_2^l + \beta(1-\pi_h)\alpha p_3.$$

As before, the left-hand side represents the gains from sticking to the product line strategy. The right-hand side represents the gains from unraveling the discounting date for part of the low valuation market.

The firm now has to satisfy two deviation constraints. This limits further the fraction of the high market segment that the firm may serve in period one. The nature of the problem, however, is the same. Although the analysis is slightly more involved, this will not change the main prediction on how the price premium, the fraction of the high segment, and the discount factor determine the firm's marketing strategy.

[5] I am grateful to Li, Hao for pointing this to my attention.

Summary of Results. The product line analysis showed that a durable good producer can reduce the cost of the Coase time commitment problem by extending its product line and/or by increasing the length of time between any two product introductions. The firm is more likely to sell a product line when the time inconsistency problem causes a greater opportunity loss, that is, when the price premium is large and/or when the high segment is large. Selling a product line allows the firm to backload sales to the low segment of the market thus reducing high valuation consumers' incentive to wait. In addition, the model hints at a theory of product life cycle:

1. Product life cycles increase as the price premium increase and as the market share of the high segment increases. They increase because the delay between any two product introductions increases or because product line length increases.

2. Prices start at higher levels and decrease more over the product life cycle as the length of the product line increases.

3. Sales are high both early and late in the product life cycle.

The model shows that a firm may choose to have short production runs and broad product line although this may be costly from a pure accounting point of view. Taken to the extreme, the argument suggests that the firm has an incentive to nurture inefficient research and development department, as well as marketing department. The gains from doing so are that it allows the firm to increase the price charged to early buyers.

5 Discussion

The marketing literature typically finds three effects to product line extensions. As emphasized in this work, broader product lines have a market fragmentation effect because each product appeals to a lower fraction of the market as the product line gets broader. By offering more variety, a broader product line also has a market expansion effect because it allows the manufacturer to satisfy a larger range of needs (Kotler, 1997). Finally, adding new product may also have a market cannibalization effect because new products may compete with existing ones (Wilson and Norton, 1989). To identify the effect of a product line on the time inconsistency problem, the model ignored both the market expansion effect and the market cannibalization effect.

I will return to the product cannibalization effect soon, but before that I want to point out that ignoring the market expansion effect was not very restrictive. The model identifies a positive return to the extension of product lines even in the absence of market expansion effect. By focusing on the fragmentation effect only, the model provides a rational for the large breadth of some product lines and for the proliferation of product variety when it seems that such activities do not increase the size of the market or the consumers' willingness to pay for the product.[6] The main lesson, then, is that there is

[6] In a different line of research, Bergen, Dutta and Shugan (1996) also show that market fragmentation can be used even when this does not increase consumer valuations (no market expansion). In their model, manufacturers offer a large variety of similar products to increase shopping costs for consumers so that retail store competition is reduced.

a potentially important strategic dimension to product line extensions that cannot be ignored. By focusing mostly on a short-term view of product line profitability, the management literature has typically overlooked this strategic dimension (Quelch and Kenny, 1994). The next two subsections develop two points about the product line solution to the time inconsistency problem that merit further attention.

The Product Line Solution to the Coase Time Inconsistency Problem. Waldman (1993, 1996) showed that a monopolist may have an incentive to introduce new products too frequently.[7] The driving force in his model is product cannibalization through premature replacement. The monopolist does not internalize how new products make old units obsolete. As an example, he claims that his model suggests that "textbook publishers have an incentive to introduce new editions that 'kill off' the market for previous editions of their popular books." He concludes that the monopolist will innovate too often.

The present model arrives to the same conclusion that the monopolist may introduce too many new products but from a completely different logic. While in Waldman's model, new product introductions were the direct result of the time inconsistency problem, they are here the cure to this problem. The reason for the difference between these two conclusions is that I assume that the monopolist can control the design and timing of new product introductions while Waldman assumes that these two variables are exogenous. In Walman's work, the monopolist cannot prevent new products from cannibalizing old ones. Although the monopolist has rational expectation about that outcome, she can do nothing to stop the product development process! Put together, the model presented here and Waldman's model suggest that the assumptions that one make on the control that the firm has over (a) the pace at which it can bring new product to the market, and (b) the *design* of the characteristics of new products, are key in determining the outcome of the time inconsistency problem. Having some control over product design allows the firm to determine whether new products will cannibalize or complement the existing product line. Having control over the pace of new product introductions allows the firm to commit to delay sales to the low market segment.

As final comment on the time inconsistency problem, it may be worth mentioning an important aspect that distinguishes the product line solution from Bullow's leasing solution and from the standard Coase scenario. Under the product line solution, the firm may try to 'damage' the low segment either by committing to sell a lower quality good (by providing less consumer service, for example) or by promoting less the good to the low segment. In the Bullow's solution as well as in the standard Coase scenario, the firm does not want to damage the low segment.[8] In contrast, it can be shown that in the product line problem, the firm may want to do damage the low segment market even if it cannot get totally rid of it. I show in the appendix that the firm may (a) lower the valuation of the low types, and (b) reduce the size of the low market segment. In other

[7] In a different line of research, Kuhn and Padilla (1996) showed that a durable monopolist will never sell a product line. The discrepancy between their prediction and common marketing practices should probably be attributed to the feature that their analysis ignores the possibility to sequentially introduce new products over time.

[8] In the Coase scenario, the firm may choose to do so only if it can completely get rid of it.

words, the firm has an incentive to lower the appeal of the product to the low segment and to spend inefficient resources promoting the product in the low market segment. By doing so, the firm profitably relaxes the second period time consistency constraint. This new effect does not appear in the standard time inconsistency problem because in that problem early prices depend only on the valuation of the low types, not on the size of the low segment. In the product line problem, however, the firm is subject not only to the standard time inconsistency problem in the third period but also to a different time inconsistency problem in the second period. In the second period, the firm would like to switch directly to the low price if the size of the remaining high segment is not substantial enough. The firm can relax this second period time inconsistency problem by lowering the profits from switching to the low segment.[9]

Product Line Pruning. A common practice in product line management is for product line managers to periodically review items in the line and to get rid of some of them. Marketing professionals call the practice of getting rid of some products 'pruning' or 'paring back' the line. The marketing literature distinguishes two occasions for pruning (Kotler, 1997). First, the product line may include deadwoods that depress profits. The other occasion for pruning is when the company is short of production capacity.

These two rationales for product line pruning are consistent with the model of product line management presented here. The analysis showed that a firm has an incentive to over-invest in new product development to delay the date on which it starts selling to the low valuation segment. It is therefore very likely that the firm will tend to carry lines that are over-extended. These extra items may not especially appeal to any consumer since their role was not so much to serve profitable market niches than to delay the sales to the low segment. It is therefore logical to prune these items from the product line when the firm turns to the low valuation segment. This model makes the additional prediction that pruning and product line rationalization should occur late in the product life cycle when prices stop to decrease, that is, when the firm starts selling to the low segment.

The other rational for pruning is also consistent with the model. The firm turns to the low segment after finishing serving the high ones. Under such a plan, the firm may suddenly need a lot of capacity to serve all the low valuation consumers. Therefore, it may be optimal to rationalize the product line and to concentrate on a few products that satisfy most of the low segment needs.

6 Summary and Conclusions

This work shows that product lines may mitigate the Coase time inconsistency problem. Product lines increase the product life cycle allowing firm to credibly delay the date on which they discount their goods. Overall, the model suggests two ways in which a firm can delay the sales to the low segment. First, the firm can commit to new products that

[9] This rational for damaging the low segment presented here differ slightly from the one proposed in Deneckere and McAffee (1996). In both models, the monopolist damages the low segment to reduce the bargaining power of the high segment. Here, however, there is an additional strategic dimension since the action of damaging the low segment is not time consistent.

take a long time to design and to bring to the market. High-technological innovations such as the Sony's waterproof walkman may illustrate this practice of artificially delaying the length of time between the first and subsequent product introductions.

Second, when the firm cannot delay the introduction of new products long enough, it may choose to fragment the high segment of the market in finer sub-segments that it serves sequentially. This second implication explains why the firm has an incentive to commit to always search for new market niches. A market niche is a small market of high valuation buyers. Finding new market niches reduces the firm's incentive to lower prices on its existing product line. A commitment to always look for new market niches has the effect of increasing early prices because consumers do not anticipate prices to fall as fast. As a prediction, the firm will tend to over-invest in research and development and marketing research. Another prediction is that product line length will be greater when the time inconsistency problem are more costly. This implies that product lines should be longer for more profitable products. This prediction is consistent with the finding that broader lines are more profitable (Kekre and Srinivasan, 1990).

Taking these two views of new product introductions to their logical end suggests a possible rational for why some firms may support research and development departments and marketing departments that are prolific but slow. Product lines that grow slowly—but never stop to grow—over time are most efficient at solving the time inconsistency problem. This prediction should be contrasted with Waldman's (1996) prediction that research and development may exacerbate the time inconsistency problem. The apparent conflict between these two conclusions can be entirely explained by the assumptions that these two works make on the control that the firm has over (a) the pace at which it can bring new product to the market, and (b) the design of the characteristics of new products. I assume that the monopolist can control the design and timing of new product introductions while Waldman makes the opposite assumption. One contribution of this work is to show that Waldman's conclusions do not hold when the firm has some control over these variables. Waldman's model is probably more relevant in environments where there is much innovation uncertainty so that the firm cannot predict if an innovation will turn out to cannibalize its existing market.

A final comment on the welfare implications of the product line strategy may be worth mentioning. Although the product line increases monopoly profits, it decreases total welfare because it delays consumption by some high valuation consumers and by all low valuation consumers. Total welfare also decreases as the length of time between any two product introductions increases. Consumer welfare also decreases under the product line strategy. It decreases for two reasons. First, consumers may have to wait longer to consume their preferred good. Second, high valuation consumers have to pay higher prices. From a welfare point of view, one should also add that the firm tends to introduce too many new products.

References

1. Bagnoli, Mark, Stephen Salant, and Joseph Swierzbinski. "Durable-Goods Monopoly with Discrete Demand." *Journal of Political Economy* 97 (6) (1989): 1458-1478.

2. Bagwell, Kyle. "Pricing to Signal Product Line Quality." *Journal of Economics and Management Strategy* (1) (Spring 1992): 151-74.

3. Bergen, Mark, Shantanu Dutta, and Steven Shugan. "Branded Variants: A Retail Perspective." *Journal of Marketing Research* (February 1996) 9-19.

4. Bullow, Jeremy. "Durable-Goods Monopolists." *Journal of Political Economy* 90 (April 1982):314-332.

5. Coase, Ronald. "Durability and Monopoly." *Journal of Law and Economics* 15 (1972):143-149.

6. Cooper, R. "Sony Corp.: The Walkman Line." Harvard Business Case 9-195-076 (1994).

7. Deneckere, Raymond, Preston McAffee. "Damaged Goods." *Journal of Economics and Management Strategy* 5 (2) (Summer 1996): 149-74.

8. Fudenberg, Drew, and Jean Tirole. "Marketing Overlapping Generations of Durable Goods: Upgrades, Trade-Ins, and Innovations." *Rand Journal of Economics* (Summer 1998):235-58.

9. Kekre, Sunder and Kannan Srinivasan. "Broader Product Line: A Necessity to Achieve Success." *Management Science* 36 (10) (1990):1216-31.

10. Kotler, Philip. *Marketing Management.* Upper Saddle River, 9^{th} edition, NJ: Prentice Hall, 1997.

11. Kuhn, Kai-Uwe and Jorge Padilla. "Product Line Decisions and the Coase Conjecture." *Rand Journal of Economics* 27 (2) (Summer 1996):391-411.

12. Lancaster, Kelvin. "The Economics of Product Variety: A Survey." *Marketing Science* 9 (3) (1990):189-206.

13. Mussa, Michael and Sherwin Rosen. "Monopoly and Product Quality." *Journal of Economic Theory* 18 (1978):301-317.

14. Quelch, John and David Kenny. "Extend Profits, Not Product-Line." *Harvard Business Review* (September-October 1994):153-160.

15. Rao, Vithala. "Pricing Models in Marketing." In *Handbooks in OR and Marketing Science* (5) Editors J. Eliashberg and G.L. Liliens. Elsevier Science Publishers, 1993.

16. Schmalansee, R. "Entry Deterrence in the Ready-to-Eat Breakfast Cereal Industry." *Bell Journal of Economics* 9 (1981): 305-327.

17. Shugan, Steven. "Branded Variants." *Research in Marketing, AMA Educators Proceeding*, Series 55. Chicago: American Marketing Association, (1989):33-38.

18. Stokey, Nancy. "Intertemporal Price Discrimination." *Quarterly Journal of Economics* 93 (August 1979):355-71.

19. Wadman, Michael. "A New Perspective on Planned Obsolescence." *Quarterly Journal of Economics* 93 (1993):273-83.

20. Wadman, Michael. "Planned Obsolescence and the R&D Decision." *Rand Journal of Economics* 27 (3) (1996):583-595.

21. Wilson, Lynn and John Norton. "Optimal Entry Timing for a Product Line Extension." *Marketing Science* 8 (1) (1989):1-17.

Appendix

I show that the firm may have an incentive ex-ante to commit to damage the low segment by lowering the appeal of the product to low valuations consumers and by spending inefficient resources reaching for low valuation consumers. Taking derivative of the profits with respect to v_l one can show that the profits increase as v_l decrease when,

$$(1-\pi_h)\frac{v_h^2}{v_h-v_l} > \frac{\beta^2}{1-\beta}.$$

As expected, the firm is more likely to damage the product for the low segment as the price premium increases and as the fraction of the high segment decreases. This last result may at first seem surprising but the intuition is quite simple. It is less costly to damage the good for the low segment as this market segment is smaller.

Assume now that the firm can reduce the size of the low type market. This can be formally done by rewriting the profits as,

$$\Pi^2 = \pi_h v_h(1+\beta-\frac{\pi_l}{\pi_h}\frac{v_l}{v_h-v_l}) + (\pi_h+\pi_l)\frac{\beta^2}{1-\beta}v_l,$$

where π_l now represents the fraction of low valuation consumers and $\pi_h + \pi_l < 1$. The firm will have an incentive to reduce the size of the low segment when the profits decrease with π_l. This occurs when

$$\frac{v_h}{v_h-v_l} > \frac{\beta^2}{1-\beta}.$$

Again, the firm is more likely to damage its low segment when the price premium is higher.

Notice that the incentives to damage the low segment that I identified here are not time consistent. In the third period, the firm will try to sell to as many low valuation consumers at a price as high as possible. In the first period, however, the firm has an incentive to commit so that it will not be able to do so in the third period.