R & D COMPOSITION OVER THE PRODUCT LIFE CYCLE

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Abstract

Firms do product R&D (making new and better products) as well as process R&D (making cheaper products). There is evidence that firms devote an increasing share of R&D to process R&D over the life cycle of a product. There is also evidence that over time, the composition of buyers of a product shifts towards the lower end of the market. This paper distinguishes product and process R&D in terms of their relationship to the composition of buyers of a product. It uses this distinction to link the aforementioned facts and to explain the change in R&D composition over time.

1 Introduction

This paper considers the effect of heterogeneity in consumer preferences on the choice of product and process R&D. In doing so, it finds a novel distinction between product and process innovations, links an observed shift in R&D composition over time to an observed change in the composition of buyers of a product over time and provides an explanation for the observed shift in R&D composition over time.

Firms engage in different types of R&D. They invest in efforts to improve the *quality* of existing products and the creation of new products. This

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is called *product R&D*. They also try to lower the *cost* of making existing products. This is called *process R&D*. For example larger memory, more screen space with a more readable screen, automatic data synchronization, digital voice recording, better handwriting recognition are some product innovations that have occurred in the hand-held computer industry recently. In contrast, better production techniques leading to lower reject rates would be an example of a process innovation in this industry.

In several industries, it has been observed that firms devote an increasing share of their R&D effort to process R&D over time. According to Klepper(1996), this is one of the defining characteristics of the product life cycle model of industry evolution in industries that have rich opportunities for both product and process R&D. Klepper(1996) cites a body of literature for a variety of industries[1] which suggests this change in R&D composition over the life cycle of a product. More recently, a study by Filson(1998) indicates that the share of R&D devoted to process R&D has increased over time in the PC industry.

A second fact that seems evident in many industries, even from a casual observation is that the composition of buyers of a product changes over its life cycle. People who buy a product when it is first introduced usually care primarily about the features or the quality of the product and are willing to pay a lot for improvements in product quality. In contrast, over time a product is usually sold increasingly to consumers at the *lower end* of the market - that is to people who care more about the price rather than the quality of the product. For example, evidence to this effect is found for computers in Flamm(1988). Similarly, in the PC market, the early consumers were the hobbyists who were willing to pay high prices for low-quality machines. Businesses, educators and home users started purchasing PCs only after improvements in the quality of PCs and a decline in their prices [see Filson(1998)].

In this paper, I connect these two facts together. I consider a monopolistic industry and solve the dynamic optimization problem of the firm. I use a discrete-choice model of consumer demand with vertical product differentiation to model consumer preferences. In my framework, potential buyers of the product differ in their willingness to pay for improvements in prod-

[1] See Abernathy et al.(1983) for automobiles, Abernathy and Utterback(1975) for a group of industries in the United States, De Bresson and Townsend(1981) for a group of industries in the United Kingdom and Utterback and Suarez(1993) and Utterback(1994) for studies of a host of different industries.

uct quality. The monopolist does both product and process R&D over time. Consequently product quality improves, production cost decreases and due to market penetration, the willingness of the marginal buyer to pay for quality improvements is lower - that is the composition of the buyers of the product shifts towards the lower end of the market - over time.

I find that the value of a product innovation (or returns to product R&D) depends on the willingness of the buyers to pay for quality improvements while the value of a process innovation (or returns to process R&D) is independent of who buys the product. Thus this paper reveals a hitherto unnoticed economic distinction between product and process R&D. This difference provides a channel through which the shift in composition of buyers over time acts to produce a shift in R&D composition over the life cycle of a product. Consumers at the higher end of the market are more willing to pay for quality improvements compared to consumers at the lower end of the market. In response to the changing needs of its clientele arising from the shift in buyer composition, the monopolist devotes more of its R&D effort to making the product cheaper over time. Put simply, R&D composition shifts over the life cycle of a product because consumers want it to be so.

Consider hand-held computers, a device that has recently become popular with the Palm Pilot. Hand-held computers are used as electronic organizers and are used amongst others by mobile professionals like doctors and corporate executives and by gadget freaks. Palm III, the updated version of the Palm Pilot and competing versions of other companies have tried to introduce more features than the original Palm Pilot. The current emphasis in the hand-held computing industry seems to be on making the product better rather than making it cheaper. Conceivably, some time in the future, hand-held computers will be used by virtually everyone, even first-graders will have them in their backpacks. Presumably, the focus will by then shift to making the device cheaper rather than adding even more features to it.

This paper is closely related to but fundamentally different from Klepper(1996) which provides an explanation for the observed shift in R&D composition over time. His explanation is based on differences in the manner in which demand for a firm's product conditions its incentives for product and process R&D. His paper builds on economies of scale and does not model consumer preferences regarding product quality. It highlights advantages of firm size for R&D, a theme emphasized by Schumpeter(1950) and provides a nice explanation of why large firms spend more on process R&D. In his model, firms that stay in an industry for a long time - successful firms - grow larger (produce more output) over time. Klepper assumes that there are scale effects in returns to process R&D but no scale effects in returns to product R&D. Consequently in his model, firms devote an increasing fraction of their R&D effort to process R&D over time.

In my framework, there are scale effects in returns to both process and product R&D. Consumer heterogeneity in willingness to pay for quality improvements is the key ingredient of my model. I also consider the case where consumers are homogeneous in their willingness to pay for quality improvements. In such a case from an economic perspective, I find that product and process R&D are simply two different but equivalent channels for research activity. I further find that with consumer homogeneity in willingness to pay for quality improvements, R&D composition is invariant over time. Both with and without consumer heterogeneity in willingness to pay for quality improvements, my framework generates results consistent with several empirical observations regarding R&D behavior. This indicates that my framework is a plausible model of R&D behavior and suggests the importance of consumer heterogeneity in willingness to pay for quality improvements for understanding product and process R&D and related issues.

The dominant design hypothesis[2] provides an alternative technology-based explanation for change in R&D composition over time. According to this viewpoint, there is considerable uncertainty about user needs and preferences regarding a product and the technological means and possibilities of satisfying them when it is first introduced. Initially R&D focuses primarily on problems regarding product design. Over time standards regarding the features, form and performance criteria for the product and a dominant design (product with standardized features and capabilities satisfying standardized performance criteria) emerge. Once a dominant design has emerged, improvements in product design try to keep standardized product features almost unchanged. Production processes increasingly become more rigid (unable to accomodate changes in product design easily) but efficient(low cost). This continuing process results in depletion of opportunities for product innovation and leads to a shift in R&D effort towards process R&D over time. I regard this as potentially complementary to my explanation.

The paper is organized as follows. Section 2 lays out the model and contains the main results of this paper. Section 3 considers some alternative scenarios. Section 4 concludes with some comments and thoughts about

[2]See for example, Mueller and Tilton(1969) or Abernathy and Utterback(1975).

further research.

2 Preferences, Production and R&D

The goal of this paper is to understand the difference between product and process R&D based on consumer preferences and to understand how the composition of buyers of a product may influence the choice of R&D composition and lead to a change in R&D composition over time. In order to sharply focus on the relationship between consumer preferences and R&D composition, I have abstracted away from several other factors which could also contribute to the shift in R&D composition over time.

2.1 The Model

I consider the industry for a non-durable product. The product is characterized by a single one-dimensional product attribute called quality denoted by s, $s \in \mathbb{R}_+$. Time is discrete. I assume that there is an exogenously given finite lifespan of n time periods, $t = 0,...,n-1$ for this industry. By the lifespan of an industry, I mean the time periods subsequent to the development of a commercially viable product till the time period after which the product becomes obsolete. Thus by time period 0, I mean the first time period in which the product is commercially introduced in the market. The development of a prototype is often very costly and the development of a successful prototype is often followed by a period of time over which the main effort is to reduce production costs since the product may not be commercially viable unless it can be sold below a certain price. Thus if one considers R&D composition right from the development of a product, one might observe initially an almost exclusive focus on product R&D corresponding to the period of developing the first prototype, then an almost exclusive focus on process R&D during the period of trying to make the product commercially viable and then both product and process R&D as the product is sold and feedback becomes available from the users. The evidence regarding the shift in R&D composition over time towards process R&D corresponds to the time after the development of a commercially viable product and this is the time-frame that I consider.

I assume an exogenously given mass of potential buyers which is invariant over these n time periods and is normalized to be one[3]. After these n time periods, the mass of potential buyers of the product is 0. One can interpret this as meaning that after n time periods, some new product comes along that renders the product in consideration obsolete. No restrictions are placed on the value of n except that it must be a finite, positive integer. Thus the results are stated and proved for a model with a finite lifespan of arbitrary length for the product.

I use the discrete-choice model of consumer demand with vertical product differentiation as in Mussa and Rosen(1978) and Maskin and Riley(1984) to model consumer preferences. This is a well-accepted model of consumer preferences with vertically differentiated products and has the empirically observed feature that higher quality products enjoy higher mark-ups. Following Mussa and Rosen(1978) and Maskin and Riley(1984), I assume that people with a high *marginal* willingness to pay for quality improvements also have a high *total* willingness to pay for the product.

Formally I assume that each potential buyer purchases either 0 or 1 unit of the non-durable product in every time period. There are two real-valued preference parameters θ and v, both non-negative and finite with $\theta \in [\theta_1, \theta_2]$ and $v \in [v_1, v_2]$. A consumer with preference parameters θ and v gets a utility of $\theta s + v - P$ from buying one unit of the product of quality s at price P. Thus utility is increasing in product quality. Further note that higher the value of θ, greater the willingness to pay for increments in product quality. Thus θ reflects a consumer's willingness to pay for quality improvements. v represents the "base value" of the product to a consumer. It is the amount that a consumer is willing to pay for a product of quality 0. The distribution of θ and v across consumers is denoted by F and is exogenously given and invariant over time. I assume that F admits a pdf f which is positive $\forall$ $(\theta, v) \in [\theta_1,\theta_2]\text{x}[v_1,v_2]$. I also assume that a consumer's choice of buying or not buying the product in any time period has no effect on the consumer's choice set or utility in subsequent time periods.

I consider two cases. One is where v is same for everyone while θ varies across consumers. In this case, F and f respectively stand for the cdf and the pdf of θ. This represents a world where consumers differ in their willingness to pay for improvements in product quality. The other case is where θ is same for everyone while v varies across consumers. In this case, F and f

[3]Product innovations could lead to an increase in the mass of potential buyers over time. I consider this case in the next section.

respectively stand for the cdf and the pdf of v. This represents the case where all consumers have the same willingness to pay for improvements in product quality. Note that in both these cases, consumers differ in their total willingness to pay for the product and consumers with a high willingness to pay for quality improvements have an overall higher willingness to pay for the product (when there is heterogeneity amongst consumers in their willingness to pay for quality improvements).

I consider a monopolistic industry with a single firm which produces the product[4]. The monopolist knows the lifespan of the product. The monopolist has a discount parameter $\beta \in [0, 1]$ and maximizes his discounted profit over the entire lifespan of the product.

The monopolist is characterized by two parameters - s and c. s denotes the quality of the product produced by the monopolist. All consumers and the monopolist agree on the value of s, that is there is complete information about product quality. c is the cost characteristic of the monopolist. The monopolist has a production function with zero fixed costs and a constant marginal cost of production c which is independent of product quality[5]. I will call (s, c), the characteristic vector of the monopolist. The initial characteristic vector of the monopolist is exogenously given. I assume parameter values to be such that the cost characteristic of the monopolist is non-negative over the lifespan of the product.

The monopolist can conduct both product and process R&D that is try to increase the value of s and lower the value of c respectively in every time period. I assume that technology for both product and process R&D is the same and is invariant over time[6]. The returns to R&D are deterministic. I assume that both product and process innovations are cumulative. This means that for any t > 0, the monopolist starts period t with the characteristic vector that it had at the end of period t-1. (s_t, c_t) denotes the characteristic vector of the monopolist at the beginning of time period t. r_t^Q and r_t^C denote

[4]While R&D competition amongst firms would definitely play a role in determining R&D composition, developing a framework with product differentiation, heterogeneous consumer preferences and simultaneous R&D and product market competition between two or more firms remains an important issue for further research.

[5]I consider the case where production cost depends on product quality in the next section.

[6]Thus my results are not due to either any difference in the relative technological opportunity to do product and process R&D or any changes in R&D technology over time. Also my results are not due to any change either in the total mass or the composition of potential buyers (with respect to willingness to pay for increments in quality) over time.

the expenditure on product and process R&D respectively by the monopolist in time period t. S_t denotes the share of process R&D in the monopolist's total R&D expenditure in time period t[7].

At the end of period t, the monopolist ends up with $s_{t+1} = s_t + g(r_t^Q)$ and $c_{t+1} = c_t - g(r_t^C)$ where $g()$ denotes the common R&D technology function[8]. I assume that $g()$ is of the form: $g(r) = ar^\lambda$ where a is a constant and $\lambda \in (0, 1)$. Note that $g()$ is a homogeneous function of degree λ. Also note that λ is the elasticity of R&D output with respect to expenditure and hence measures efficiency of R&D technology.

One could argue that my assumptions regarding the technological opportunity for product and process R&D - namely that these opportunities are constant over time and a constant and identical elasticity of product and process R&D - are not a good description of R&D conditions as observed in various industries. While differences in the opportunities for process and product R&D and declining technological opportunities for R&D do have a role in determining R&D composition[9], I abstract away from these aspects of R&D conditions in order to focus sharply on the relationship between consumer preferences and R&D composition. While discussing the intuition behind my results in a later subsection, I briefly discuss how my results might be affected if we assume for example that it becomes increasingly difficult to improve product quality or lower production costs over time.

There is a numeraire good. Price of the product, utility that a consumer gets from buying the product and R&D expenditure, costs, revenues and profits of the monopolist are measured in terms of this numeraire good.

At the beginning of a period, the monopolist first decides how much to spend on product R&D and how much to spend on process R&D during that time period. I assume that the monopolist has no financial constraints regarding choice of R&D budget in any time period[10]. Then the outcome of the monopolist's R&D effort is realised as per the R&D technology.

I assume that the product is produced, bought and sold at the end of each period, that is after the outcome of the monopolist's R&D effort in that

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[7]Thus, $S_t \equiv \frac{r_t^C}{r_t^C + r_t^Q}$.

[8]The functional form of returns to innovation that I have assumed is not something new in the literature, see for example Klepper(1996).

[9]For studies that focus on this issue, see for example the dominant design literature.

[10]I briefly consider the case where the monopolist has financial constraints while deciding on how much to spend on product and process R&D in the next section.

period has been realized. Thus in period t, the monopolist sells a product of quality s_{t+1} and it takes the monopolist c_{t+1} to produce each unit of the product. Further I assume that the monopolist cannot price discriminate between various consumers[11]. If the utility to a consumer from buying one unit of the product sold by the monopolist is non-negative, the consumer buys one unit of the product from the monopolist; else the consumer buys nothing from the monopolist. The monopolist has no capacity constraints and faces no potential threat of entry.

2.2 Preliminary results

In any time period t, the monopolist takes two decisions. It decides how much to spend on product and process R&D in that time period. It also decides how much of the product to sell (or equivalently what price to charge for the product) in that time period.

First I will look at the monopolist's decision regarding quantity sold in any time period. Since I am considering a non-durable product, the monopolist's quantity choice in a given period does not affect its future sales. Also note that the monopolist decides on how much to sell in a period based on its characteristic vector at the end of the period. In mathematical terms, in any time period t, the monopolist solves the following problem to decide how much to sell in that period:

$$max_{x \in [0,1]}[p(x, s_{t+1}) - c_{t+1}]x \tag{1}$$

where $p(x, s)$ denotes the price at which a fraction x of potential buyers buy one unit each of the product of quality s.

Notation: Let MR(x,s) denote the marginal revenue curve of the monopolist with respect to x - the fraction of market served - when selling a product of quality s.

Assumption: MR(x,s) strictly decreases in x.

This guarantees a unique solution to the monopolist's profit-maximization problem and thus allows us to talk unambiguously about quantity sold by the monopolist in any time period. This is true for example if v is same

[11] I briefly consider the case where the monopolist can price discriminate between various potential buyers in the next section.

for everyone and θ is uniformly distributed across the potential buyers (or if θ is same for everyone and v is uniformly distributed across the potential buyers)[12].

Also note that the functional form that has been assumed for consumer preferences implies that the monopolist's marginal revenue is strictly increasing in product quality as long as it has a positive value.

Now I will consider the monopolist's R&D decision in any time period. Consider the case where the monopolist starts a time period with the characteristic vector (s,c) and chooses expenditure on product and process innovations such that it ends the time period with the characteristic vector (s',c'). Let $\pi(s, s', c, c')$ denote the monopolist's profit in that time period alone. Then $\pi(s, s', c, c')$ is given by the following equation:

$$\pi(s, s', c, c') = max_{x \in [0,1]}[p(x, s') - c']x - g^{-1}(s' - s) - g^{-1}(c - c') \qquad (2)$$

Here $g^{-1}(s' - s)$ is the cost of improving product quality from s to s' while $g^{-1}(c - c')$ is the cost of lowering production cost from c to c' in a single time period.

Since I have assumed product and process innovations to be cumulative, the monopolist's choice of product and process R&D in any time period affects not only its profit in that time period but also affects its profit in subsequent time periods.

Notation: Let $V(t, s, c)$ denote the value function of the monopolist at the beginning of a time period when the monopolist starts off with the characteristic vector (s,c) and the product has a further lifespan of t periods.

Then the value function is given by the following equation:

$$V(t, s, c) = max_{s',c'} \pi(s, s', c, c') + \beta V(t - 1, s', c') \qquad (3)$$

Since there are n time periods, the monopolist's dynamic optimization problem is $V(n, s_0, c_0)$. Equivalently it can be expressed by the following equation:

[12]More generally, this is true if v is same for everyone and F(θ_1 + (θ_2 − θ_1)x) = x^{α} where x ∈ [0, 1] and $\alpha > 1$ (or if θ is same for everyone and F(v_1 + ($v_2 - v_1$)x) = x^{α} where x ∈ [0, 1] and $\alpha > 1$.)

$$V(n, s_0, c_0) = max_{[s_{t+1}, c_{t+1}]_{t=0}^{t=n-1}} \sum_{k=0}^{n-1} \beta^k \pi(s_k, s_{k+1}, c_k, c_{k+1}) \quad (4)$$

Now I will look at change in product quality, production cost and quantity sold by the monopolist over time.

Assumption: $\theta s_0 + v > c_0$ for some $(\theta, v) \in [\theta_1, \theta_2]x[v_1,v_2]$.

This assumption implies that the monopolist will sell a positive quantity of the product in time period t=0 even if it did not do any R&D during this period. However, the fact that the monopolist sells a positive quantity means that the monopolist has an incentive to do both process R&D (since this would lower production costs and hence lead to more profits on every unit sold) and product R&D (since this would increase product quality and hence lead to more profits on every unit sold through a higher price) at $t = 0$. Since $\lim_{r \to 0} g'(r) = \infty$, the monopolist will do a positive amount of both product and process R&D at $t = 0$. Since innovations are cumulative and marginal revenue is increasing in product quality, the monopolist's output is non-decreasing over time. Thus the assumption made above implies that the monopolist will sell a positive quantity in every time period. Then by the same argument as above, we have the following result:

Lemma 1: Product quality increases and per unit cost of production decreases in every time period.

From the firm's dynamic optimization problem [equation (4)] and the functional form assumption about $g()$, by an application of the envelope theorem, it follows that the optimal product and process R&D expenditure sequence of the monopolist satisfies the following FONC's:

FONC for r_t^C [process R&D]; t=0,...,n-1:

$$[\sum_{k=t}^{n-1} \beta^{k-t} x_k] g'(r_t^C) = 1 \quad (5)$$

FONC for r_t^Q [product R&D]; t=0,...,n-1:

$$[\sum_{k=t}^{n-1} \beta^{k-t} p_2(x_k, s_{k+1}) x_k] g'(r_t^Q) = 1 \quad (6)$$

where $p_2(x, s)$[13] denotes the partial derivative of $p(x, s)$ with respect to s and x_k denotes the fraction of potential buyers who buy the product in time period k. In my framework, quantity sold by the monopolist in time period k equals x_k since the mass of potential buyers has been assumed to be 1. Note that $p_2(x_k, s_{k+1})$ is simply the willingness of the marginal buyer to pay for quality improvements in time period k and equals the value of θ for the marginal buyer in time period k.

In my framework, either all consumers have the same value for θ or $\theta \in [\theta_1, \theta_2]$ where θ reflects a consumer's willingness to pay for improvements in the quality of the product. Thus there is a finite upper bound on the rate of increase in a consumer's utility corresponding to an increase in product quality. Also since this is a discrete choice model of consumer demand and the mass of consumers is invariant over time, there is a finite upper bound to quantity sold by the monopolist in any time period. Further R&D technology exhibits diminishing marginal returns. Hence from equations (5) and (6), it follows that there is an upper bound for the monopolist's product and process R&D expenditure in any single time period. Since the industry has a finite lifespan, this implies the following result:

Lemma 2: $\exists$ finite numbers say s_{max} and c_{min} such that $s_n \leq s_{max}$ and $c_n \geq c_{min}$.

Note that both process and product R&D would tend to lead to an increase in quantity sold by the monopolist. This in turn would lead to a greater incentive on the part of the monopolist to do both product and process R&D. Lemma 2 implies that the monopolist's dynamic optimization problem is well-defined. Also note that parameter values can be chosen such that c_{min} is non-negative.

2.3 Difference between product and process R&D

Both product and process R&D achieve the same economic end - they increase the price-cost margin of a firm. Product R&D does this by increasing the price that buyers are willing to pay for the product due to improvements

[13]Since I have assumed that f, the density of the preference parameters is positive in the entire range of possible parameter values, $p(x, s)$ is continuous and differentiable for the two cases that I consider.

in product quality - that is by increasing demand for the product - while process R&D does this by lowering the production cost of a firm. Many economic studies that look only at R&D and are not concerned about the different kinds of R&D treat product and process R&D as equivalent. Conversely, any study that looks at product and process R&D and not just at R&D must clearly distinguish between the two kinds of R&D.

Different ideas have been put forth regarding the distinction between product and process R&D. One is the technological idea on which the dominant design hypothesis is based - namely that process innovations can be meaningfully attempted only after problems regarding product design have been tackled and hence product innovations (or R&D) precede process innovations (or R&D) in the scheme of things. In this view, there does not necessarily exist an economic distinction between the two kinds of R&D.

Another idea is that put forth by Klepper(1996) and Cohen and Klepper(1996a). According to this view which is based on the findings of Levin et al.(1987), product innovations can be licensed or sold in a disembodied form while process innovations can be exploited only through a firm's own output. Consequently process innovations are exploited through a firm's own output more heavily than product innovations. For example in Klepper(1996), the return to product R&D is independent of while the return to process R&D is directly related to a firm's output.

According to another view. process R&D lowers production cost while product R&D simply serves to lessen the competition faced by a product by differentiating it from other similar products. This could come about through product variety in a horizontal model of product differentiation [for example, see Eswaran and Gallini(1996)] or through a non-essential product innovation whose sole purpose is product differentiation and which serves no other useful purpose from an economic point of view [for example, see Rosenkranz(1996)].

I find a different distinction between product and process R&D which is stated in the following proposition.

Proposition 1: (Difference between product and process R&D) *The returns from process R&D are independent of the composition of buyers of a product while the returns from product R&D depend on the composition of buyers of a product.*

Proposition 1 follows from equations (5) and (6). From equation (5), it follows that the incentive to do process R&D in any time period is conditioned solely by quantity sold in that and subsequent time periods till the product becomes obsolete.

On the other hand, in any time period k, the monopolist sells its product which is of quality s_{k+1} to a fraction x_k of the mass of potential buyers. Hence the monopolist charges a price of $p(x_k, s_{k+1})$ in period k. This is the price at which the marginal buyer - the buyer whose total willingness to pay for the product is the top x_kx100 percentile value amongst the values for total willingness to pay for the product across all potential buyers - is indifferent between buying and not buying the product. Thus $p_2(x_k, s_{k+1})$ represents what this marginal buyer is willing to pay for increments in product quality. From equation (6), it follows that the incentive to do product R&D in any time period is conditioned by the willingness of the marginal buyer in that and in subsequent periods of the life cycle of the product to pay for quality improvements.

Another way of looking at Proposition 1 is that if a firm is able to lower its production cost by a dollar, it saves a dollar on every unit that it produces irrespective of who buys the product. On the other hand, if a firm improves its product quality, the value of the quality improvement depends on the willingness of the buyers to pay for it.

If consumers differ in their willingness to pay for quality improvements, then the first-order necessary conditions for process and product R&D are not equivalent - thus from an economic perspective, product and process R&D are two distinct, non-equivalent activities in such a case. However, if consumers are homogeneous in their willingness to pay for quality improvements - that is θ is same for all consumers - equations (5) and (6), the first-order necessary conditions to do product and process R&D are equivalent[14]. Thus with homogeneity in willingness to pay for quality improvements across consumers, from an economic perspective there is no difference between product and process R&D.

In the next subsection, I show how this simple distinction between product and process R&D translates into a shift in R&D composition over the life cycle of a product through a change in buyer composition resulting from market penetration.

[14] In this case, equation(6) - the condition for product R&D - is simply equation (5) - the condition for process R&D - scaled by the factor θ - the common value of willingness to pay for quality improvements across all consumers.

2.4 Evolution of R&D composition

I first consider the evolution of quantity sold - that is market penetration - over time.

Assumption: Even if $s = s_{max}$ and $c = c_{min}$, the market is not covered.

Now from Lemma 1, we know that product quality increases and production cost decreases over time. Also, note that both with consumer heterogeneity and consumer homogeneity in willingness to pay for quality improvements, marginal revenue increases with increments in product quality. These two together with the assumption made above lead to the following result:

Lemma 3: Quantity sold by the monopolist in a time period increases with time over the lifespan of the industry.

The following Proposition characterizes evolution of R&D composition over the life cycle of a product when there is heterogeneity amongst consumers in their willingness to pay for quality improvements.

Proposition 2: (Heterogeneity in willingness to pay for quality improvements) S_t, the share of process R&D in total R&D expenditure is an increasing function of time.

Corollary to Proposition 2: Further, if $\beta = 0$:
(a) amount spent on process R&D is increasing in output.
(b) average product of process R&D $\equiv \frac{g(r_t^C)}{r_t^C}$ is decreasing in output.

Proof: See the Appendix.

Note that Proposition 2 in combination with Lemma 3 means that the monopolist does relatively more of process R&D when it produces a higher level of output. This has potential significance in explaining a cross-sectional relationship that has been observed between firm size and R&D composition. I discuss this in the concluding section.

The corollary is in agreement with several empirically observed relationships between firm size and R&D and firm size and R&D productivity. I discuss this in a later subsection.

If consumers are homogeneous in their willingness to pay for quality improvements, then the evolution of R&D composition over the life cycle of a product is as follows:

Proposition 3: (Homogeneity in willingness to pay for quality improvements) S_t, the share of process R&D in total R&D expenditure is invariant over time.

Corollary to Proposition 3: Further, if $\beta = 0$:

(a) amount spent on both product and process R&D are increasing in output.

(b) Average product of process R&D $\equiv \frac{g(r_t^C)}{r_t^C}$ and average product of product R&D $\equiv \frac{g(r_t^Q)}{r_t^Q}$ are decreasing in output.

(c) Total R&D spending is increasing in output.

Proof: See the Appendix.

The corollary again is consistent with empirically observed relationships between firm size and R&D and firm size and R&D productivity.

2.5 Intuition behind results

The key to Proposition 2 is the fact that with heterogeneity in willingness to pay for quality improvements across consumers, willingness of the marginal buyer to pay for quality improvements is lower over time. There are two main factors behind this phenomenon. One is the positive correlation between willingness to pay for quality improvements and total willingness to pay for the product. The other is the increase in quantity sold by the monopolist over time.

In this framework, since both product and process innovations are cumulative, product quality improves and production cost decreases over time. Since in my framework, marginal revenue is increasing in product quality, quality increments coupled with the decrease in production cost lead to an increase in quantity sold by the monopolist over time. Since this is a discrete choice model of consumer demand, an increase in quantity sold implies that the product is sold to a larger number of people. With consumer heterogeneity in willingness to pay for quality improvements, there is a positive correlation across consumers between total willingness to pay for the product and willingness to pay for quality improvements and hence selling to more people means selling to people with a lower willingness to pay for improvements in product quality. Consequently the willingness of the marginal buyer to pay for quality improvements is lower over time. Incentive for process R&D depends on level of output while incentive for product R&D depends both on the level of output and the marginal buyer's willingness to pay for quality improvements. As a result, with consumer heterogeneity in willingness to pay for quality improvements, R&D effort shifts towards process R&D over time.

With homogeneity in willingness to pay for quality improvements across consumers, the monopolist's "marginal return from process R&D relative to the marginal return from product R&D" is constant over time. This follows simply from the fact that with consumer homogeneity, since all consumers have the same willingness to pay for quality improvements, the willingness of the marginal buyer to pay for quality improvements is invariant over time. Consequently the monopolist always spends the same fraction of its R&D budget on process R&D.

One could argue that there are factors that could contribute to quality improvements becoming more important over time. For example, later on, certain segments or niches of potential buyers may want to buy specific high-quality versions or applications of the original product. I have assumed that the monopolist sells only one variety of the product. However, in such a case, the monopolist will more likely sell more than one product variety - say a high-quality version and a low-quality version - of the product. Presumably, people with a high willingness to pay for quality improvements will be the ones buying the high-quality version. Correspondingly, while the monopolist would do more of product R&D regarding the high-quality version, it would do even more of process R&D regarding the low-quality version since increasingly only people with lower and lower willingness to pay for quality improvements will be buying the low-quality version. Over time, we would expect the high-quality version to become a lot more improved compared to the low-quality version - maybe to the extent that it would be classified as a new product - and also more and more people to switch to it. This would again lead to a shift towards process R&D for the high-quality product which would be further accentuated when an even higher quality version of the product comes along. Thus we would expect to see cycles of R&D composition - my framework describes one such cycle - with a shift from product to process R&D along any one cycle.

Also note that in my framework, the competition that the product faces from potential alternative products is invariant over time. However, one would expect a product to face stiff competition from alternative products when it is first introduced and the competition to become weaker as the quality of the product improves over time - in fact significant improvements in product quality may establish the product as clearly superior to the other alternative products. In such a case, one would expect R&D to be geared more towards product R&D initially with the incentive for product R&D diminishing over time as the product becomes established as clearly superior over alternative products.

Note that the specific functional form that I have assumed for R&D technology does not play a critical role in obtaining my results. In the proof of Proposition 2, we see that $\frac{g'(r_t^C)}{g'(r_t^Q)}$ - "return from doing one more unit of process R&D relative to the return from doing one more unit of product R&D" - decreases over time. This follows simply from the fact that the willingness of the marginal buyer to pay for quality improvements is lower over time. With diminishing marginal returns, this suggests that process R&D relative to product R&D increases over time. Similarly, in the proof of Proposition 3, we see that $\frac{g'(r_t^C)}{g'(r_t^Q)}$ is invariant over time. The specific functional form that I have assumed for g() is simply a sufficient condition to guarantee an inverse relationship between "marginal return from process R&D relative to the marginal return from product R&D" and the ratio of process R&D to product R&D.

Also note that with consumer homogeneity, R&D composition is invariant over time regardless of how quantity sold by the monopolist evolves over time. In fact Proposition 3 can be obtained without any of the assumptions that I have made regarding F() and MR(,).

I have assumed returns to product and process R&D to be independent of the level of product quality or production cost. If instead I assume that improving product quality and lowering production cost becomes increasingly more difficult with increments in product quality and decline in production cost, then this would lower the incentive for both product and process R&D over time. The shift in R&D composition over time would then depend on the relative magnitudes of these effects.

2.6 Comparison with empirical observations

In addition to generating the empirically observed shift in R&D composition over time when consumers differ in their willingness to pay for quality improvements, my framework generates results consistent with several empirical observations.

Numerous studies have found that in general firms with larger output tend to spend more on innovative activities, especially in more research and development intensive industries[15]. Also, certain empirical studies suggest an inverse relationship between R&D productivity and firm size[16]. In my framework, the corollaries to Proposition 2 and 3 provide results consistent with these observations. Also for certain parameter values (for example if F is uniform and r - the elasticity of R&D output with respect to R&D expenditure - $< \frac{1}{2}$), total R&D expenditure in my framework rises less than proportionally with firm size as has generally been found [see Klepper(1996)].

3 Alternative scenarios

3.1 Perfect price discrimination

I have assumed that the monopolist is unable to price discriminate between different consumers. One way to price discriminate between different consumers would be to sell several models with differing levels of product quality at different prices. However sufficiently high fixed costs for each model produced would rule out production of more than one model of the product. A natural question to ask is what happens if the monopolist could indeed price discriminate, at least to some extent. I consider the case where consumers differ in their willingness to pay for quality improvements with the further assumption that θ is distributed uniformly over $[\theta_1, \theta_2]$ and assume that the monopolist can perfectly price discriminate between various potential buyers. I still find that the monopolist devotes an increasing fraction of total R&D effort to process R&D over time. On the other hand, with consumer homogeneity in willingness to pay for quality improvements and the assumption that v is uniformly distributed over $[v_1, v_2]$, I find that if the monopolist can perfectly price discriminate, then it spends an increasing fraction of its R&D expenditure on product R&D over time. Thus even with perfect price discrimination, consumer heterogeneity in willingness to pay for quality improvements generates the observed shift in R&D composition over time while consumer homogeneity fails to do so. Hence I believe that the assumption of

[15]For a review of these studies see Cohen and Klepper (1996b).

[16]See Bound et al.(1984), Acs and Audretsch(1988, 1991), Scherer(1965), White(1983).

no price discrimination is not crucial for my results.

3.2 Financial constraints

I have assumed that the monopolist does not face any financial constraints while deciding how much to spend on product and process R&D. I also consider the case where the monopolist has a limited R&D budget in every time period which is exogenously given and is unrelated to sales or profits made by the monopolist in previous periods or expected sales in future periods. I find that even in this case, with consumer heterogeneity in willingness to pay for quality improvements, the monopolist devotes an increasing share of total R&D budget to process R&D over time. On the other hand, with consumer homogeneity in willingness to pay for quality improvements, the monopolist devotes the same fraction of total R&D budget to process R&D in every time period.

Thus the assumption of no financial constraints regarding the choice of R&D budget is not essential for my results at least as long as the constraints on the R&D budget are unrelated to sales or profits of the monopolist. The case where the monopolist has a limited R&D budget and the amount of R&D budget is related to sales or profits is more complicated and requires further exploration.

3.3 Quality-dependent cost

I have assumed that the per unit cost of production of the good is independent of its quality. I also consider the case where the per unit cost of producing the good depends on its quality. This would be the case if making a product of better quality required better materials which cost more or a greater labor input or labor with greater skills who can be hired only at higher wages.

One formulation of the case where production cost is positively related to product quality is to assume that the cost of producing a good of quality s is additively separable in c and s (for example cost of producing a good of quality s being $c + s$). This would be the case if making a product of better quality mainly involved using materials which cost more. This case is equivalent to the framework that I have considered. Hence, my results hold in this scenario.

Another formulation is the case when the cost of producing a product is multiplicative in c and s. This would be the case where producing a product of a certain quality required a certain number of labor hours and producing a product of higher quality either involved the use of more skilled workers who must be paid a higher wage or required the use of more labor hours. Formally, I look at the case where the cost of producing one unit of the product of quality s is cs - thus c here denotes the cost of making one unit of a product of unit quality in this case and process innovations lower this cost. I make some further minor assumptions that ensure that the monopolist's problem is well-defined in this case.

In this case, a product innovation has two effects. On one hand, as before it increases demand for the product. As before, the amount of product R&D depends on the willingness of the marginal buyer to pay for quality improvements. On the other hand, in this case a product innovation also raises the production cost for the good. Since the amount by which a product innovation raises the production cost depends on c, the amount of product R&D in this case also depends on the value of c. Process innovations lower the value of c and thus increase the incentive for product R&D over time. Also note that in this case, the benefit from a process innovation depends not only on the amount of quantity sold but also on the quality of the product. In fact, higher the product quality, greater the benefit of a process innovation and this is another channel through which the incentive for process innovation increases over time. In this case, I find that unless the amount of reduction in c is very large compared to the amount of increase in s[17], R&D composition still shifts towards process R&D over time.

3.4 Quality-dependent mass of potential buyers

One could argue that many markets have expanded over time not just by bringing in more buyers who have a lower willingness to pay for the product but also through product innovations that have opened up new uses for the product. For example[18], innovations in radios opened up the possibility of using radio receivers to receive entertainment broadcasts which was used for home entertainment. Prior to that, radios were used mainly by ships who wanted to be able to have communication with the shore and other ships. There is no reason to believe that the potential new buyers of a product would have a different structure of preferences than the old buyers. I consider the

[17]The magnitudes of the amount of reduction in c and the amount of increase in s depend on parameter values.

[18]I would like to thank an anonymous referee for suggesting this example.

case where the mass of potential buyers is not constant over time but is a function of the product quality. However, I assume that the distribution of preference parameters across the potential buyers of a product is always the same. In this case, product innovations have an additional effect - they lead to an increase in the mass of potential buyers. Consequently, there is an additional term in the returns to product R&D - namely the price-cost margin multiplied by the increase in the mass of potential buyers due to an increase in the amount of product R&D. I find that unless this additional term is very large, there is still a shift towards process R&D over time.

4 Comments and further research:

This paper extends the existing literature in several directions. Till date, most studies of product and process R&D that have explicitly modeled the demand side have either used the horizontal product differentiation model or have adopted the demand structure from Dixit (1979). In these models, firms doing product R&D over time means that firms bring out many different versions of the same product, none of which is inherently better than the others. While this is certainly true in some cases, these models ignore the continual improvement in product attributes that comes about through product R&D as is often the case with many products. Further these studies consider product and process R&D in a static framework. While the framework used in this paper has been used elsewhere to look at several important economic problems, to the best of my knowledge this is the only paper other than Bonnano et.al(1998) to use the model of vertical product differentiation for studying product and process R&D[19].

This paper distinguishes product and process R&D in terms of their relationship to consumer preferences. It uses this distinction to link the change in the composition of buyers of a product to the change in composition of R&D for the product over time and to provide an explanation for the shift in R&D composition over the life cycle of a product. A nice thing about this explanation is that firms do precisely what their buyers want them to do -

[19]Bonnano et.al(1998) use this framework to look at how the form of competition (Bertrand or Cournot) affects both the adoption or non-adoption of cost-reducing innovations and the choice between adopting a product or a process innovation. However, they do not use this framework to distinguish between the two kinds of R&D or the other issues addressed here.

they spend relatively more on process R&D over time to satisfy the needs of their clientele. An interesting extension of this paper would be to embed this model in a framework with product ladders. In such a framework, a product would not suddenly become obsolete after a certain period of time. Instead, new products would attract buyers with high willingness to pay for quality improvements away from old products, further reinforcing the shift in R&D composition towards process R&D over time.

The dominant design hypothesis provides a technology-based explanation for the shift in R&D composition over time. Klepper(1996) explains this shift through the difference in how demand for a firm's product conditions its incentives for product and process R&D. His explanation is based on scale effects being present for process R&D and absent for product R&D. I also provide an explanation based on demand factors. However, my explanation is based on the change in composition of buyers of a product with respect to their willingness to pay for product innovations over time. It would be interesting to try to sort the relative importance of these three factors in shaping R&D composition over time[20].

Scherer(1991) finds in a cross-sectional study of firms that larger firms tend to devote a greater fraction of their total R&D spending on process R&D. The result is true even when inter-industry differences in technological opportunity are taken into account. Cohen and Klepper(1996a) Pavitt et al.(1987) and Freeman(1982) have also found similar evidence.

With consumer heterogeneity in willingness to pay for quality improvements, I find a positive relationship between level of output of the monopolist and fraction of R&D budget spent on process R&D. Although this relationship arises due to the fact that in my framework level of output and composition of buyers with respect to their willingness to pay for quality improvements (when consumers differ in their willingness to pay for quality improvements) move in the same direction over time, it raises the following question: Is it necessary that in order to sell higher levels of output, a firm would have to sell to customers with a lower willingness to pay for increments in product quality? If that is indeed the case, then we would expect large firms to devote a greater fraction of their R&D effort to process R&D. More work needs to be done in this direction[21]. It seems that consumer

[20]For some work in this direction, see Klepper and Simons(1997).

[21]Cohen and Klepper(1996a) have provided an explanation of this phenomenon based on the assumption that there are scale effects to returns from process R&D and no scale effects to returns from product R&D.

heterogeneity in willingness to pay for increments in product quality would perhaps be a key ingredient in explaining the relationship between firm size and composition of a firm's R&D effort.

5 Appendix

Proof of Proposition 2: From the FONC for product and process R&D we get:

$$\frac{g'(r_t^C)}{g'(r_t^Q)} = \frac{\sum_{k=t}^{n-1} \beta^{k-t} p_2(x_k, s_{k+1}) Q_k}{\sum_{k=t}^{n-1} \beta^{k-t} Q_k} \tag{7}$$

Some algebraic manipulation yields:
For any t, t = 0,...,n-2:

$$\frac{\sum_{k=t}^{n-1} \beta^{k-t} p_2(x_k, s_{k+1}) Q_k}{\sum_{k=t}^{n-1} \beta^{k-t} Q_k} = \frac{\sum_{k=t+1}^{n-1} \beta^{k-t} p_2(x_k, s_{k+1}) Q_k}{\sum_{k=t+1}^{n-1} \beta^{k-t} Q_k} + Q_t[\sum_{k=t+1}^{n-1} \beta^{k-t}(p_2(x_t, s_{t+1}) - p_2(x_k, s_{k+1}))Q_k] \tag{8}$$

Thus

$$\frac{g'(r_t^C)}{g'(r_t^Q)} = \frac{g'(r_{t+1}^C)}{g'(r_{t+1}^Q)} + Q_t[\sum_{k=t+1}^{n-1} \beta^{k-t}(p_2(x_t, s_{t+1}) - p_2(x_k, s_{k+1}))Q_k] \tag{9}$$

With consumer heterogeneity, for any value of product quality, total willingness to pay for the product is perfectly correlated with the value of the preference parameter θ, that is the person with the highest value of θ has the highest total willingness to pay for the product, the person with the second-highest value of θ has the second-highest total willingness to pay for the product and so on. This follows from the functional form that has been assumed for the utility function and the assumption that v is same for everyone. Therefore, we get the following relationship:

$\forall$ k = 0,...,n-1:

$$p(x_k, s_{k+1}) = F^{-1}(1 - x_k)s_{k+1} \tag{10}$$

Hence,

$$p_2(x_k, s_{k+1}) = F^{-1}(1 - x_k) \tag{11}$$

From Lemma 3, we know that x_k is strictly increasing in k. My assumption that F admits a pdf f and $f > 0 \; \forall \; \theta$ implies that $F^{-1}(1-x)$ is strictly decreasing in x. Hence, $p_2(x_k, s_{k+1})$ is strictly decreasing in k. Combining this with equation (9), it follows that $\frac{g'(r_t^C)}{g'(r_t^Q)}$ decreases with time.

From the assumption that $g()$ is a homogeneous function of degree r, we get:

$$\frac{g'(r_t^C)}{g'(r_t^Q)} = \frac{1}{(\frac{r_t^C}{r_t^Q})^{1-\lambda}}. \tag{12}$$

Since $0 < \lambda < 1$, a lower value of $\frac{g'(r_t^C)}{g'(r_t^Q)}$ implies a higher value of $\frac{r_t^C}{r_t^Q}$. Since, $\frac{g'(r_t^C)}{g'(r_t^Q)}$ decreases with time, it follows that $\frac{r_t^C}{r_t^Q}$ increases with time. ■

Proof of Corollary to Proposition 2: (a) follows by putting $\beta = 0$ in equation(5) - the FONC for process R&D - and the assumption of diminishing marginal returns from R&D. (b) follows from the assumption regarding the functional form of g(). ■

Proof of Proposition 3: With consumer homogeneity in willingness to pay for quality improvements $p_2(x_k, s_{k+1}) = \theta \; \forall$ k = 0,...n-1. Hence from equation (9), it follows that $\frac{g'(r_t^C)}{g'(r_t^Q)}$ is invariant over time. Hence from equation(12), it follows that $\frac{r_t^C}{r_t^Q}$ is constant over time. ■

Proof of Corollary to Proposition 3: (a) follows by putting $\beta = 0$ in equation(5) and equation(6), the FONC for process and product R&D respectively and the assumption of diminishing marginal returns from R&D. (b) follows from the assumption regarding the functional form of g(). (c) follows from (a). ■

6 References

Abernathy, William J. and Utterback, James M. " A Dynamic Model of Process and Product Innovation." *Omega, 1975, 3(6)*, pp. 639-56.

Abernathy, William J.; Clark, Kim B. and Kantrow, Alan M. *Industrial Renaissance: Producing a competitive future for America. 1983* New York: Basic Books.

Acs, Zoltan J. and Audretsch, David B.,"Innovation in Large and Small firms." *AER, 1988, 78(4)*, pp. 678-90.

—— "R&D, Firm Size and Innovation Activity." in Zoltan J. Acs and David B. Audretsch, eds., *Innovation and technological change: An international comparison 1991*. New York: Harvester Wheatseaf, pp. 39-59.

Bonnano, Giacomo and Haworth, Barry. "Intensity of competition and the choice between product and process innovation." *International Journal of Industrial Organization 16(1998)*, pp. 495-510.

Bound, John; Cummins, Clint; Grilliches, Zvi; Hall, Browny H. and Jaffe, Adam. "Who Does R&D and Who Patents?" in Zvi Grilliches, ed., *R&D, patents and productivity*. Chicago: University of Chicago Press for the National Bureau of Economic Research, 1984, pp. 21-54.

Cohen, Wesley M. and Klepper, Steven."Firm Size and the nature of Innovation within Industries: The Case of Process and Product R&D." *Review of Economics and Statistics, May 1996a, LXXVIII(2)*, pp. 232-243.

—" A Reprise of Size and R&D." *Economic Journal, July 1996b, 106(437)*, pp. 925-951.

De Bresson, C. and Townsend, J."Multivariate Models For Innovation: Looking at the Abernathy-Utterback Model with Other Data." *Omega, 1981, 9(4)*, pp.429-36.

Dixit, A. "A Model of Duopoly suggesting a Theory of Entry Barriers." *Bell Journal of Economics, Vol.10*, pp. 20-32.

Eswaran, Mukesh and Gallini, Nancy. "Patent Policy and the Direction of Technological Change." *The Rand Journal of Economics, Winter'96, Vol27, No.4*, pp.722-746.

Filson, Darren. "Product and Process Innovations in the Life Cycle of an Industry." unpublished manuscript, 1998.

Flamm, Kenneth. *Creating the Computer. 1988* Washington, DC: The Brookings Institution.

Freeman, Christopher. *The Economics of Industrial Innovation, 1982* Cambridge, MA: MIT Press.

Klepper, Steven. "Entry, Exit, Growth, and Innovation over the Product Life Cycle." *The American Economic Review, June 1996, 86(3)*,pp. 562-583.

Klepper, Steven and Simons, Kenneth. "Technological Extinctions of Industrial Firms: An Inquiry into their Nature and Causes" *Industrial and Corporate Change, March 1997, V.6, No. 2*,pp. 379-460.

Levin, Richard C., Klevorick, Alvin K., Nelson, Richard R. and Winter, Sidney G. "Appropriating the Returns from Industrial R&D." *Brookings*

Papers on Economic Activity, 1987, pp. 783-820.

Maskin, Eric and Riley, John. "Monopoly with incomplete information." *Rand Journal of Economics, Vol 15, No. 2, Summer 1984*, pp. 171-196.

Mueller, D.C. and Tilton, J.E. " R&D Costs As a Barrier to Entry." *Canadian Journal of Economics, November 1969, vol.2*, pp. 570-579.

Mussa, M. and Rosen, S. "Monopoly and Product Quality." *Journal of Economic Theory, vol.18, 1978*, pp. 301-317.

Pavitt, K., M. Robson, and J. Townsend. "The Size Distribution of Innovating Firms in the UK:1945-1983." *Journal of Industrial Economics 1987, 35*, pp. 291-316

Rosenkranz, Stephanie."Simultaneous Choice of Process and Product Innovation." Discussion Paper No. 1321, CEPR, January 1996.

Scherer, F.M. "Changing Perspectives on the Firm Size Problem" in Zoltan J.Acs and David B. Audretsch (eds.), *Innovation and Technological Change: An International Comparison* (New York: Harvester Wheatsheaf, 1991).

——"Firm Size, Market Structure, Opportunity, and the output of Patented Inventions." *AER, 1965, 55(5)*, pp. 1097-125.

Schumpeter, J.A. *Capitalism, Socialism and Democracy. 1950* Harper: New York, 3rd edn.

Suarez, Fernando F. and Utterback, James M. "Innovation, Competition and Industry Structure." *Research Policy, February 1993, 22(1)*, pp. 1-21.

Utterback, James M. *Mastering the Dynamics of Innovation. 1994* Harvard Business School Press, Boston, Massachusetts.

White, Alice Patricia. *The dominant firm. 1983* Ann Arbor, MI: UMI Research Press.