Changes in Product Attributes and Costs
as Drivers of New Product Diffusion and Substitution

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1.  Introduction

Technological innovations result in new products that expand markets and/or take market share from existing products. They generally do so incrementally, through a diffusion or substitution process. For example, Bass (1969) describes the diffusion process as one where innovators adopt without being influenced by others, while imitators adopt only after coming in contact with customers who communicate the new product benefits to them. A similar perspective is that of Rogers (2003) who suggests diffusion occurs as adopters shift from innovators to early adopters to the early majority. Adoptions then fall off as the late majority and laggards are the only ones left to adopt. Again, customers are influenced mostly by whether other customers have already adopted or not. These descriptions of diffusion do not explicitly consider the influence of the operations function during this diffusion process, but instead focus on communication channels. We will refer to this as the marketing-oriented perspective.

We interpret the work of Christensen and Raynor (2003), abbreviated C/R, to suggest a somewhat different perspective. They implicitly suggest adoption progresses due to changes in product attributes. The product performance and production process are not static – a product that fails to meet customer demands at one point can do so later, even in the face of increasing customer demands. This occurs when the improvements grow at a faster rate than the growth in actual requirements. Implicit in the C/R framework is that the purchase decision is based on the (known) performance of the product as compared to the customer’s own (known) requirement, rather than whether someone else has bought. As contrasted with the marketing-oriented perspective discussed above, this framework focuses on how changes in product attributes and production processes (costs) influences purchase decisions over time, and thus we call this the operations-oriented perspective.
To develop a model focusing on the operations-oriented perspective, we build on the linear reservation price curve framework of Schmidt and Porteus (2000), S/P. A customer’s reservation price is the most she is willing to pay for the product, while a product’s reservation price curve is the plot of customer reservation prices starting with the customer willing to pay the most and progressing down to the one who would pay the least. We assume both customer willingness-to-pay and production costs change over time, creating the diffusion and substitution processes. We seek insight into what drives this process and how it might play out over time in terms of market shares and market segments to which the old and new products sell over time.

In our framework, at any time a product can be described by two parameters, its depth (maximum reservation price minus unit cost) and breadth. A product’s breadth is related to the slope of its reservation price curve; if the slope is relatively shallower, assuming a fixed depth, then all reservation prices are more similar and the product appeals more broadly. Thus changes in product attributes and costs over time manifest themselves as changes in depths and breadths. Measures related to the speed at which the new product’s depth and breadth are changing relative to the old product are called the coefficient of depth and the coefficient of breadth. We assume changes in depth and breadth follow an S-curve (logistic), where the S-coefficient describes the degree of non-linearity in changes in depth and breadth over time.

2. **Relationship to Other Literature**

One of the most influential papers surrounding diffusion and substitution is Bass (1969). Norton and Bass (1987) extend Bass to a model for multiple product generations. Numerous other extensions and related works take into account marketing and operations factors such as price, advertising, supply limitations, and product introduction timing. See Mahajan et al. (1995) for further review. Our model contributes to this literature by explicitly modeling diffusion and substitution as resulting from changes in product costs and attribute levels.

3. **Review of Linear Reservation Price Framework**

Our linear reservation price framework is based on S/P but differs in two notable respects. First, we allow a product’s reservation price curve (and the corresponding part-worths) to vary with time. Second, in place of a one-shot purchase, we assume a customer is considering the purchase of one unit of one product per time period (e.g., one unit per year).

We assume there are only two products, the old and new, and that a product is described
by $n$ attributes. The part-worth ascribed by each customer to the performance along each dimension is assumed known, with reservation price equal to the sum of the part-worths. A customer is assumed to buy the product offering the highest positive surplus (difference between reservation price and sales price) or nothing. Sorting customers from those willing to pay the most to the least and plotting reservation prices, we assume a continuous and linear curve. The product with a shallower-sloped curve is labeled B for broad appeal, while the other is labeled N, for niche appeal. The intercept and slope of product N’s curve are normalized to one. Either the old or new product can be B, and we make no assumptions as to whether one reservation price curve lies above the other or whether they cross. If competing firms sell products N and B, the Nash equilibrium prices, $p_j(t)$, $j \in \{N, B\}$, are given by $S/P$ which in turn determine sales $q_j(t)$ and profits $\pi_j(t) = \left[p_j(t) - c_j(t)\right]q_j(t)$, where the product costs, $c_j(t)$, are assumed known. When only one firm sells both products, prices, sales and profits are based on profit maximization. Firms and customers are assumed to act myopically.

We define product $j$’s depth as $m_j(t) := v_j(t) - c_j(t)$, where $v_j(t)$ is the intercept of the reservation price curve. A product’s depth represents the deepest discount that a firm would tolerate relative to the maximum reservation price. Depth ratio is $m(t) := m_j(t)/m_j(t)$, where $j$ and $J \in \{N, B\}$ and $j \neq J$, with $j$ the new product. Let $k(t)$ denote the (negative) slope for product B. We call $k(t)$ the breadth factor as it effectively defines the breadth for both products.

4. Substitution as a Result of Changes in Product Depths and Breadths

In a substitution process, at the time of introduction of a new product (denoted by $t_0$) the market share of the new product typically starts close to zero and then grows. We focus on the case where the new product eventually displaces the old (the ratio of market shares grows to infinity at some time denoted by $t_w$). In our model, the ratio of market shares is given by:

$$S_B^D(t) = \frac{q_B(t)}{q_N(t)} = \frac{\left[2 - k(t)\right]m(t) - k(t)}{k(t)\left[2 - k(t)\right] - k(t)m(t)}$$

and

$$S_N^M(t) = \frac{q_N(t)}{q_B(t)} = \frac{m(t)-1}{1/k(t) - m(t)},$$

where $S_B^D$ applies to the case involving two firms and $S_N^M$ applies to the case involving one.

We normalize time such that $t_0 = 0$ and $t_w = 1$. In the well-known S-curve framework, described by Christensen (1992b) for example, the capability of a technology improves slowly at first, then the rate of technology improvement increases, and later the rate falls off again because
the technology has matured. Similarly, the rate of change in depth and breadth may vary over
time. Our S-curve specifications are \( m(t) = m(t_0) + dy(t) \) and \( k(t) = k(t_0) + by(t) \), where
\( y(t) = \left[ \alpha + \beta \left/ \left(1 + e^{-\sigma(t-5)}\right) \right. \right] \): \( \sigma \) effectively determines the “curviness” of the S-curve, \( d \) is the
coefficient of depth and \( b \) the coefficient of breadth. The terms \( d \) and \( b \) represent the cumulative
changes in depth and breadth between \( t_0 \) and \( t_w \). At \( t_0 = 0 \) we must have \( y(0) = 0 \) and at \( t_w = 1 \) we must have \( y(1) = 1 \), yielding \( \alpha = -\gamma/(1-2\gamma) \) and \( \beta = 1/(1-2\gamma) \) where \( \gamma = 1/(1+e^{0.5\sigma}) \).

This leaves \( d, b, \) and \( \sigma \) as the only unknowns. We call \( \sigma \) the S-coefficient.

5. Empirical Fit of Data

We fit our model to data from the disk drive and microprocessor industries. We seek the
\( d, b, \) and \( \sigma \) that minimize the sum of the squared differences between observed and predicted
logarithms of the ratios of market shares. Best-fit coefficients were found using Solver followed
by a check over the space to insure the result was not merely a local minimum. See Figure 1.

![Graph](image.png)

Figure 1. Fitting the model to empirical disk-drive data (left) and microprocessor data (right).

From the late 1970s through the 1980s, several new generations of smaller drives were
introduced, progressing from 14-inch, to 8-inch, to 5.25-inch, to 3.5-inch units. Each new
generation had a new firm as the market leader. While the storage capacity of a new smaller
drive was initially much less than that of the older larger drive, capacity continually increased
and production cost continually decreased within each generation. These changes affect customer
reservation prices and product costs, thus changing depth and breadth. We assume a starting
point (based on industry history) of \( k(t_0) = 0.30 \) and \( m(t_0) = 0.177 \). Our empirical data for
market share are from Christensen (1992a).

Regarding microprocessors, we use the example of the new Intel Pentium-III (P-3),
which is a differentiated substitute for the old P-2, marketed by the same firm. Increases in chip clock speed and decreases in costs (attributable to the learning curve) contribute to changes in the depth ratio and breadth factor. We assume $k(t_0) = 0.8$ and $m(t_0) = 1.0$. Market share ratios were calculated from Dataquest (2003) data.

6. **Discussion and Summary**

While Bass (1969) assumes diffusion is due to communication and finds the coefficients of innovation and imitation, we link diffusion and substitution to changes in product attributes (reservation price curves) and costs and find the coefficients of depth and breadth, along with an S-coefficient. The coefficient of depth describes the extent to which the new product’s depth of maximum plausible markup changes relative to that of the old product. Two things can increase a product’s depth: Either its cost decreases, or customers enhance their view of it (increasing its maximum reservation price). The coefficient of breadth describes the extent to which a product becomes relatively more broadly attractive over time. The good fits between empirical results and our model support our hypothesis that diffusion/substitution can result not only from communication, but also from relative improvements in product features and costs over time.

**References**


