

PART II

PRICING DECISIONS AND MARKETING MIX

9 Strategic pricing of new products and services*

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Abstract

This chapter organizes and reviews the literature on new product pricing, with a primary focus on normative models that take a dynamic perspective. Such a perspective is essential in the new product context, given the underlying demand- and supply-side dynamics and the need to take a long-term, strategic, view in setting pricing policy. Along with these dynamics, the high levels of uncertainty (for firms and customers alike) make the strategic new product pricing decision particularly complex and challenging. Our review of normative models yields key implications that provide (i) theoretical insights into the drivers of dynamic pricing policy for new products and services, and (ii) directional guidance for new product pricing decisions in practice. However, as abstractions of reality, these normative models are limited as practical tools for new product pricing. On the other hand, the new product pricing tools available are primarily helpful for setting specific (myopic) prices rather than a dynamic long-term pricing policy. Our review and discussion suggest several areas that offer opportunities for future research.

1. Introduction

Pricing of new products is an especially challenging decision, given its critical strategic importance and complexity. Contributing to the complexity are the uncertainty faced by the firm on both demand and supply sides, the dynamic (changing) environment and operating conditions, and the need for a long-term decision-making perspective, given that the firm's pricing decision in the current period is likely to impact future outcomes. Thus this chapter focuses primarily on new product pricing strategies that take a long-term perspective and recognize the dynamics driven by demand- and supply-side conditions over the extended time horizon.

Past reviews of new product pricing models include Kalish (1988). Monroe and Della Bitta (1978), Rao (1984, 1993) and Gijssbrechts (1993) cover new product pricing as part of their broader reviews of pricing. Also relevant are the reviews of new product diffusion models incorporating price and/or other marketing mix elements by Kalish and Sen (1986) and Bass et al. (2000). This chapter provides a selective and updated review and synthesis of strategic new product pricing models, focusing primarily on analytical models, but also describing relevant empirical research.

1.1 Dynamic pricing of new products: skimming versus penetration

Dean's ([1950] 1976) seminal article identifies new product pricing policy as 'the choice between (1) a policy of high initial prices that skim the cream of demand [skimming] and (2) a policy of low prices from the outset serving as an active agent for market penetration [penetration pricing]' (p. 145). The rationale for these two extreme strategies lays the foundation for our subsequent review. As we shall see, some of the policy prescriptions call for

* Comments and suggestions from Vithala R. Rao, Jehoshua Eliashberg and an anonymous reviewer are gratefully acknowledged.

a combination of penetration and skimming at different stages of the product life cycle, while others may be nuanced versions of these basic strategies. Dean identifies important elements of the new product pricing problem, including defining the firm's objective in terms of maximizing discounted profits over the planning horizon, taking into account customer and competitive dynamics over that period (see also Dean, 1969).

In a skimming strategy, prices begin high to extract the maximum surplus from customers willing to pay premium prices for the new product. Subsequently, prices decline as more price-sensitive segments are targeted in turn, to implement an intertemporal price discrimination strategy – ‘an efficient device for breaking the market up into segments that differ in price elasticity of demand’ (Dean [1950] 1976, p. 145). Dean also argues that this is a safer policy given uncertainty about demand elasticity, in that the market is more accepting of prices being lowered over time than the other way round. In addition, costs are likely to drop over time on account of market expansion and improved efficiency through experience (scale economies and experience curve effects). Price skimming helps to recover up-front investments in product development and introductory marketing. On the other hand, the high price level invites competition, unless the firm can extend its monopoly status (e.g. via patent protection).

Under a penetration pricing strategy, the objective is to aggressively penetrate the market by low prices. Some conditions under which penetration pricing makes sense are:

- price-sensitive customers in the mainstream market;
- short- and long-run cost benefits from scale economies and experience curve effects (cost-side learning), respectively;
- product characteristics that are well understood by mainstream customers (suggesting incremental rather than discontinuous innovations); and
- the threat of competitive entry.

Typically, a penetration pricing strategy would require the resources to support the rapid ramp-up in production, distribution and marketing of the product. Strategically, short-run profits are being sacrificed for future benefits – in terms of lower costs and a stronger market position, which can serve as sources of competitive advantage.

1.2 Skimming versus penetration: empirical evidence of managerial practice

When do managers use skimming or penetration pricing strategies in practice? Noble and Gruca (1999) surveyed managers responsible for pricing at firms supplying differentiated, capital goods in business-to-business markets, to learn about management practice and its relationship to theory. For new products, they identify three strategies – price skimming, penetration pricing and experience curve pricing (which is a particular case of penetration pricing).¹ The latter two involve low initial prices and have similar determinants relative to skimming – lower product differentiation, incremental innovation, low costs,

¹ Noble and Gruca's study is not limited to new products. They organize the strategies by the pricing situation for both new and mature products and then, for strategies within each pricing situation, by the conditions expected to favor the choice of a particular strategy. The three new product strategies were chosen by 32 percent of all respondents across all situations (skimming 14 percent, penetration 9 percent, and experience curve pricing 11 percent).

price elastic demand and available production capacity. The distinction is the primary source of cost advantage – experience curve pricing exploits learning by doing, while penetration pricing focuses on scale economies.

Managers were more likely to use skimming (with high relative price) in markets with high product differentiation when facing a cost disadvantage due to scale economies. Penetration pricing (with low relative price) was chosen when there was a cost advantage due to scale economies and total market demand was price elastic. Finally, experience curve pricing was used when there was high product differentiation, the product was not a major innovation, and there was low capacity utilization. Thus managerial practice is consistent with theory, except for the finding that experience curve pricing appears to be used in markets with high product differentiation, perhaps because the firms using this strategy are market followers cutting prices now to drive down costs in anticipation of future commoditization of the market.

Turning to a different industry (pharmaceuticals), Lu and Comanor (1998) investigate the temporal price patterns for new drugs and the principal factors affecting prices. Pharmaceutical price behavior appears consistent with Dean's conjecture. Significant innovations follow a modified skimming strategy, with prices at launch displaying substantial premium over existing substitutes, then declining over time. Most 'me too' new products follow a penetration strategy with launch prices below the competition, and then possibly increasing. Competition exerts downward pressure on prices. The nature of the application has pricing implications as well: drugs for acute conditions have larger premiums than those for chronic conditions.²

1.3 A framework for reviewing models of new product pricing

In the next two sections, we build on our discussion of skimming and penetration strategies to review analytical models of new product pricing that offer normative guidelines. With this in mind, we identify, in Table 9.1, the product, customer and firm/industry-related dimensions pertinent to the new product pricing decision that we employ to structure our review. Section 2 reviews models in a monopolistic setting, while Section 3 examines competitive models. Section 4 briefly discusses approaches to setting new product prices in practice. We conclude with a summary of the current status and directions for future research, in Section 5.

2. Normative models in a monopolistic setting

We organize our review of monopolistic models on the basis of the specification of the underlying demand model: models using an aggregate-level diffusion model for their demand specification (Section 2.1); models that consider the individual customer adoption decision explicitly in the diffusion process (Section 2.2); models incorporating strategic customers with foresight (Section 2.3); and models focusing on successive generations instead of a single product (Section 2.4). Section 2.5 summarizes the strategic new product pricing implications in a monopoly. Table 9.2 lists the key features and findings of selected monopolistic models.

² For more on pricing of pharmaceuticals, see the chapter in this volume by Kina and Wosinska (Chapter 23).

Table 9.1 *New product pricing models: key dimensions*

Dimension	Characteristic	Remarks and implications
Product	Nature: frequency of purchase; physical product vs service	The frequency of purchase significantly impacts the dynamics of pricing. With durables, cumulative sales can adversely affect product demand owing to saturation; with nondurables, repeat purchase can build brand loyalty. Differences between physical products and services have pricing implications in general (see chapter).
	Degree of innovativeness	Products can range from radically new or breakthrough at one end of the spectrum to incremental (or 'me too') at the other. This dimension has a critical impact on the demand dynamics, via its influence on customer behavior and competitive advantage.
	Degree of customer involvement	With high-involvement products (e.g. large ticket items), customers are more inclined to make the purchase decision carefully, after collecting information to reduce the high degree of perceived risk, relative to low-involvement products (which are often purchased on impulse). For a new product, adoption behavior and, in the aggregate, the dynamics of demand are affected by the degree of involvement.
	Diffusion (positive network) effects	Positive network effects result in an increase in the value of products as the number of products in use in the market (e.g. fax machines) increases. This is a direct network effect. Similar positive effects can also be indirect – for example, customers' valuations of products (e.g. hardware) may increase from a greater availability of complementary products (e.g. software) as the installed base of customers expands (the 'complementary bandwagon effect', Rohlfs, 2001). The same dynamic of increasing likelihood of adoption with expanding usage base can result on account of 'word of mouth' effect (Rogers, 2003). We use the term <i>diffusion effect</i> to refer to the positive impact of market penetration (cumulative sales) on demand, whatever the underlying mechanism driving this dynamic.
Customer	Uncertainty, risk attitude and learning	In the new product context, customer uncertainty about product performance is a pertinent issue. When uncertainty is explicitly considered, customers' attitude toward risk and the possibility of learning to resolve uncertainty become relevant factors as well as influencers of customers' willingness to pay.
	Heterogeneity (in price sensitivity and other characteristics)	While price sensitivity obviously affects price, the heterogeneity in price sensitivity (and, more generally, in preferences) across customers provides opportunities for price-based segmentation, including intertemporal price discrimination. Individual-level price sensitivity may change over time, as in the case of increasing loyalty through product experience. The demand model may be specified at the aggregate level from the outset, or else built up from the

Table 9.1 (continued)

Dimension	Characteristic	Remarks and implications
	Type of customer	disaggregate level. The disaggregate approach allows for explicit consideration of heterogeneity on key behavioral dimensions (such as willingness to pay). The degree of customer sophistication (myopic versus far-sighted and strategic) affects the pricing decision. The type of buyer (organizational versus consumer) also affects the nature of buyer behavior, with implications for pricing practices and policy. In particular, organization buyers may be fewer in number but more powerful and sophisticated than individual consumers.
Firm and Industry	Cost structure (static and dynamic)	Apart from the 'static' aspects of the cost structure (fixed versus variable costs and economies of scale), experience curve effects – which result in a lowering of costs with the cumulative volume of units produced and sold – have a dynamic impact on new product pricing policy.
	Uncertainty and learning	There is uncertainty on the firms' part about demand for the new product as well as other aspects of the environment (e.g. the competition). Such uncertainty can impact on firm behavior. There may also be the incentive to learn (e.g. via experimentation).
	Competition	The competitive situation – the presence of competition and its nature – is a critical factor in the pricing decision. We classify new product pricing models on the basis of whether or not they consider competition. Among models considering competition, a distinction can be made between competition among incumbent firms and potential competition from future entrants (Chatterjee et al., 2000).

2.1 Aggregate-level diffusion models

There is a rich stream of literature in marketing on new product pricing models (typically normative in nature) based on aggregate-level diffusion models best exemplified by Bass (1969). A key idea underlying these diffusion models (applied to first-time sales of durables) is that the rate of sales at any point in time depends on the cumulative sales (or market penetration), i.e.

$$dN/dt = f(N(t)) \tag{9.1}$$

where $N(t)$ is cumulative sales (or penetration), dN/dt is the demand (rate of sales), and $f(\cdot)$ is the function operator. In particular, the Bass model takes the form

$$dN/dt = \left[p + q \frac{N(t)}{\bar{N}} \right] [\bar{N} - N(t)] \tag{9.2}$$

where \bar{N} is the size of the total adopter population, and p and q are the coefficients of innovation and imitation respectively. The underlying demand dynamics are driven by

Table 9.2 Normative models in a monopolistic setting

	(1) Robinson and Lakhani (1975)	(2) Dolan and Jeuland (1981)	(3) Kalish (1983)	(4) Bass and Bultez (1982)	(5) Krishnan et al. (1999)
1. Product characteristics	Durables	Durables and nondurables	Durables	Durables	Durables
2. Customer behavior/demand:					
(a) Demand drivers/sources of demand dynamics	Cumulative sales (diffusion and saturation effects), price	Durable: cumulative sales (diffusion and saturation effects), price. Nondurable (trial plus repeat): cumulative sales and price; saturation effects for trial	Cumulative sales (diffusion and saturation effects) or time (exogenous diffusion pattern), and price	Time (exogenous diffusion pattern), price	Cumulative sales (diffusion and saturation effects), price (current level and rate of change)
(b) Heterogeneity	No (aggregate-level specification)	No (aggregate-level specification)	No (aggregate-level specification)	No (aggregate-level specification)	No (aggregate-level specification)
(c) Uncertainty/learning?	No	No	No	No	No
(d) Strategic customers?	No	No	No	No	No
3. Firm/industry:					
(a) Experience curve effects?	Yes	Yes	Yes	Yes	Yes
(b) Uncertainty/learning?	No	No	No	No	No
(c) Decision variable(s)	Price	Price	Price	Price	Price
(d) Type of equilibrium (if customers are strategic)	Not applicable (myopic customers)	Not applicable (myopic customers)	Not applicable (myopic customers)	Not applicable (myopic customers)	Not applicable (myopic customers)

4. Key results/
pricing
implications
- Optimal price may *increase* initially, and then *decline*
 - Durables: optimal price *increases* initially, and then *declines* if diffusion effect sufficiently strong; otherwise price monotonically *declines*
 - Nondurables: optimal price monotonically *declines* if decline in trial (due to saturation) is greater than growth of repeat, and *increases* otherwise
 - For durables (with diffusion and saturation effects), optimal price *increases* initially, and then *declines* if diffusion effect sufficiently strong; otherwise price monotonically *declines*
 - In case of exogenously specified life cycle, optimal price monotonically *declines* with experience curve effect on cost
 - Optimal price may *increase* initially (if the diffusion price sensitivity parameter and discount rate are sufficient small), and then *declines*
 - Optimal price monotonically *declines* with decreasing cost (experience curve effect)

	(6) Chen and Jain (1992)	Durables	(7) Raman and Chatterjee (1995)	Durables	(8) Huang et al. (2007)	Durables	(9) Jeuland (1981)	Durables	(10) Kalish (1985)	Durables and nondurables
1. Product characteristics										
2. Customer behavior/demand:										
(a) Demand drivers/sources of demand dynamics	Cumulative sales (diffusion and saturation effects), price, uncertain discrete shock	Cumulative sales (diffusion and saturation effects), price, uncertainty (stochastic disturbance)	Cumulative sales (diffusion and saturation effects), price, reliability	Cumulative sales (diffusion and saturation effects), price, reliability	Cumulative sales (diffusion and saturation effects), price, reliability	Cumulative sales (diffusion and saturation effects), price, reliability	Cumulative sales (information diffusion), distribution of reservation prices	Cumulative sales (information diffusion), distribution of reservation prices	Cumulative aware and cumulative adopters (awareness dynamics with saturation and diffusion effects), distribution of reservation prices	Cumulative aware and cumulative adopters (awareness dynamics with saturation and diffusion effects), distribution of reservation prices

Table 9.2 (continued)

	(6) Chen and Jain (1992)	(7) Raman and Chatterjee (1995)	(8) Huang et al. (2007)	(9) Jeuland (1981)	(10) Kalish (1985)
(b) Heterogeneity	No (aggregate-level specification)	No (aggregate-level specification)	No (aggregate-level specification)	Heterogeneity in reservation price	No (aggregate-level specification)
(c) Uncertainty/learning?	No	No	No	Yes – information reduces uncertainty	Yes – information reduces uncertainty
(d) Strategic customers?	No	No	No	No	No
3. Firm/industry:					
(a) Experience curve effects?	Yes	Yes	No	Yes	Yes
(b) Uncertainty/learning?	Yes – random, discrete shock (Poisson process); no learning	Yes – demand uncertainty; no learning	No	No	No
(c) Decision variable(s)	Price	Price	Price, length of warranty, product reliability	Price	Price, advertising
(d) Type of equilibrium (if customers are strategic)	Not applicable (myopic customers)	Not applicable (myopic customers)	Not applicable (myopic customers)	Not applicable (myopic customers)	Not applicable (myopic customers)
4. Key results/pricing implications	<ul style="list-style-type: none"> Impact of uncertainty on price policy greater if probability and/or magnitude of random shock is larger 	<ul style="list-style-type: none"> Demand uncertainty – <i>increases</i> initial price – <i>reduces</i> the price slope (which is declining) 	<ul style="list-style-type: none"> For particular set of parameter values, price and warranty period <i>decline</i> over time 	<ul style="list-style-type: none"> Same as aggregate-level models, i.e. optimal price <i>increases</i> initially, and then <i>declines</i> if diffusion effect sufficiently strong; otherwise price 	<ul style="list-style-type: none"> Industry prices will <i>increase</i> when diffusion effect is dominant and <i>decrease</i> when saturation effect is dominant

- Impact of uncertainty can either reinforce or counterbalance price dynamics in deterministic case
 - Price path experiences jump at time of shock
- *reduces* sensitivity of initial price and slope to changes in other demand parameters and discount rate
- Lower cost firm will have higher market share (with common industry prices)
 - Given cost-side learning, high-cost firm will produce more to reduce (or even reverse) cost disadvantage

monotonically *declines*

- Actual shape of diffusion curve influenced by reservation price distribution

(11) Horsky (1990) Household durables

(12) Besanko and Winston (1990) Durables

(13) Narasimhan (1989) Durables

(14) Moorthy (1988) Durables

(15) Balachander and Srinivasan (1998) Durables

1. Product characteristics			
2. Customer behavior/demand:			
(a) Demand drivers/sources of demand dynamics	Cumulative eligible adopters (saturation and diffusion effects), preference, distribution of wage rates	Distribution of reservation prices, price, future price expectations	Distribution of reservation prices, price, future price expectations
(b) Heterogeneity	Heterogeneity in wage rate	Heterogeneity in reservation price	Heterogeneity in reservation price
(c) Uncertainty/learning?	Yes – information (cumulative sales) reduces uncertainty	No	Yes – uncertain about cost in Period 1
(d) Strategic customers?	No	Yes – perfect foresight	Yes – perfect foresight

Table 9.2 (continued)

	(11) Horsky (1990)	(12) Besanko and Winston (1990)	(13) Narasimhan (1989)	(14) Moorthy (1988)	(15) Balachander and Srinivasan (1998)
3. Firm/industry:					
(a) Experience curve effects?	Yes	No	No	No	Yes
(b) Uncertainty/learning?	No	No	No	No	No
(c) Decision variable(s)	Price	Price	Price	Price	Price
(d) Type of equilibrium (if customers are strategic)	Not applicable	Subgame-perfect Nash	Subgame-perfect Nash	Subgame-perfect Nash	Subgame-perfect Nash
4. Key results/pricing implications	<ul style="list-style-type: none"> Optimal price <i>declines</i> monotonically if the diffusion effect is weak. If the diffusion effect is sufficiently strong, then prices start <i>low</i> and <i>increase</i> before <i>declining</i> If the diffusion effect is especially strong, the initial price may be <i>lower</i> than initial cost 	<ul style="list-style-type: none"> Optimal price for firm facing myopic customers <i>declines</i> monotonically over time and is (a) <i>higher</i> (in case of myopic customers) and (b) <i>lower</i> (in case of strategic customers) in any time period (except last) than single-period optimal price For any given penetration level, optimal price 	<ul style="list-style-type: none"> With customer expectations and diffusion, optimal price path follows cyclical pattern. Within each cycle, price declines monotonically Stronger diffusion effect implies shorter cycles 	<ul style="list-style-type: none"> It is <i>not</i> possible for a low-cost monopolist to signal high cost by charging a high price in Period 1. The optimal decision is to price in Period 1 to reveal true cost 	<ul style="list-style-type: none"> Low-experience firm credibly signals its cost structure by charging a <i>higher</i> first-period price than in full-information case

always *lower* for rational customers relative to myopic customers. Also, price declines at a *lower* rate

	(16) Dhebar and Oren (1985)	(17) Judd and Riordan (1994)	(18) Zhao (2000)	(19) Bayus (1992)	(20) Padmanabhan and Bass (1993)
1. Product characteristics	Networked service (e.g. telecom)	Nondurable, experience good	Nondurable, experience good	Successive generations of durables	Successive generations of durables
2. Customer behavior/demand:					
(a) Demand drivers/sources of demand dynamics	Cumulative sales (positive network effect), distribution of reservation prices, subscription price	Distribution of customer's reservation price, product experience, price	Distribution of customer's reservation price, advertising (creates awareness), price	1st gen. (replacement sales only): cumulative 2nd gen. sales, prices, time; 2nd gen: cumulative 2nd gen. sales, prices	1st gen: cumulative firm sales (saturation effect), own price; 2nd gen: cumulative firm sales and own price, plus fraction of 1st gen. demand
(b) Heterogeneity	Heterogeneity in reservation price	Heterogeneity in reservation price	Heterogeneity in reservation price	No (aggregate-level specification)	No (aggregate-level specification)
(c) Uncertainty/learning?	Yes – uncertain about future network growth (i.e. this can be only partially anticipated)	Yes – uncertain about product quality; learning from product use	Yes – uncertainty about product quality; inference drawn from firm's decisions (price, advertising)	No	No
(d) Strategic customers?	Yes – anticipate future network growth	Yes	Yes	No	No

Table 9.2 (continued)

	(16) Dhebar and Oren (1985)	(17) Judd and Riordan (1994)	(18) Zhao (2000)	(19) Bayus (1992)	(20) Padmanabhan and Bass (1993)
3. Firm/industry:					
(a) Experience curve effects?	Yes	No	No	No	Yes
(b) Uncertainty/learning?	No	Uncertainty about quality – resolved by private information	No	No	No
(c) Decision variable(s)	Subscription price	Price	Price, advertising	Price	Price
(d) Type of equilibrium (if customers are strategic)	Subgame-perfect Nash	Bayes-Nash (subgame-perfect)	Separating equilibrium	Not applicable – myopic customers	Not applicable – myopic customers
4. Key results/pricing implications	<ul style="list-style-type: none"> • Optimal subscription price monotonically <i>increases</i> over time • Anticipation of future network growth by customers and a lower discount rate both <i>lower</i> price for a given network size 	<ul style="list-style-type: none"> • When customers are uncertain about product quality and form beliefs based on product experience and price, high-quality monopolist can signal quality by pricing <i>above</i> full-information price in Period 1. As consumer learning increases over time, price <i>declines</i> toward full-information level 	<ul style="list-style-type: none"> • When customers are uncertain about product quality, a high-quality firm will price <i>higher</i> and spend less on advertising than in full-information situation, regardless of the quality-marginal cost relationship 	<ul style="list-style-type: none"> • Optimal price for 2nd gen. <i>declines</i> monotonically over time if 2nd gen. sales come from normal and/or discretionary replacements as long as fraction of normal replacements large enough. Otherwise, 2nd gen. price may be <i>increasing</i> initially 	<ul style="list-style-type: none"> • Prior to 2nd gen. entry, diffusion (saturation) effect <i>decreases (increases)</i> 1st gen. price • After 2nd gen. entry, higher substitution rate drives 1st gen. price closer to, and 2nd gen. price away from, myopic optimum levels. Positive impact of 1st gen. price (sales) on 2nd gen. demand implies <i>higher (lower)</i> 1st gen. price

- The firm has incentive for initial investment in temporary quality improvement
- For sufficiently large fraction of replacement sales, 1st gen. price *increases* (*decreases*) if 2nd gen. sales come entirely from discretionary (normal) replacements

(21) Kornish (2001)

1. Product characteristics	Successive generations of durables
2. Customer behavior/demand:	
(a) Demand drivers/sources of demand dynamics	Prices and qualities of 1st and 2nd gen. distribution of reservation prices
(b) Heterogeneity	Heterogeneity in reservation prices
(c) Uncertainty/learning?	No
(d) Strategic customers?	Yes – perfect foresight

Table 9.2 (continued)

(21) Kornish (2001)	
3. Firm/industry:	
(a) Experience curve effects?	No
(b) Uncertainty/learning?	No
(c) Decision variable(s)	Price
(d) Type of equilibrium (if customers are strategic)	Subgame-perfect equilibrium
4. Key results/pricing implications	<ul style="list-style-type: none"> • With customers with perfect foresight, it is possible for an equilibrium to exist in case there is improvement from 1st to 2nd gen. in real value terms, as long as firm does not offer special upgrade price for 2nd gen. to 1st gen. owners

the diffusion effect captured by the first term on the right-hand side of (9.2), which is increasing in cumulative sales or market penetration, and the saturation effect captured by the second term, which is decreasing in cumulative sales. The diffusion effect drives the dynamics early in the life cycle (when penetration is low), while the saturation effect dominates later – thus demand is increasing in cumulative sales (or market penetration) initially, but decreasing later in the life cycle. The models discussed in this section extend the basic model (9.1) by explicitly incorporating price as a variable influencing demand. Our discussion complements and updates the previous reviews by Kalish (1988); Kalish and Sen (1986); and Bass et al. (2000).

Normative models seek to derive the price trajectory over the planning period to optimize some objective (e.g. the discounted profit stream), given the demand function (based on a diffusion model), and appropriate initial, terminal and/or boundary conditions. Dynamic optimization typically involves the use of calculus of variations or optimal control (Kamien and Schwartz, 1991). Mathematically, the basic version of the problem may be stated as:

$$\max_{p(t)} \int_0^T e^{-rt} [p(t) - c(N(t))] (dN/dt) dt \tag{9.3}$$

$$\text{subject to: } dN/dt = f(N(t), p(t)); N(0) = 0; N(T) = \varphi$$

where $c(N(t))$ is the marginal cost, which may decline in cumulative sales under cost-side learning, and φ represents the salvage value. The demand specification usually incorporates price in one of three ways (Kalish and Sen, 1986):

Multiplicative price influence The general form of the demand model is

$$dN/dt = f(N(t)) \cdot h(p(t)) \tag{9.4}$$

where $h(p(t))$ is a decreasing function of price at time t , $p(t)$. This model was first employed by Robinson and Lakhani (1975; Table 9.2(1)) and later by Dolan and Jeuland (1981; Table 9.2(2)); see also Jeuland and Dolan (1982). Dolan and Jeuland also analyze a non-durable goods model, where the sales rate is the sum of initial purchases given by (9.4) and repeat purchases proportional to the number of users $N(t)$.

Kalish (1983; Table 9.2(3)) considers a variety of demand specifications, including the multiplicative price influence model in (9.4). The Robinson and Lakhani (1975) and Dolan and Jeuland (1981) models are special cases of Kalish’s more general formulation. The analysis provides insight into the effects of the different dynamic drivers of long-term profit on the optimal price path for a durable good. We summarize the key implications below:

- If demand is a function of price alone (i.e. there are no demand-side dynamics), the optimal price declines monotonically over time under cost-side learning and a positive discount rate. Cost-side learning reduces the optimal price below the myopic optimum, to trade off short-term profits for lower costs in future. This result applies to both durables and nondurables.

- In the presence of diffusion and saturation effects on demand, and assuming a zero discount rate, the optimal price path increases as long as demand is increasing in market penetration (i.e. the diffusion effect dominates), then decreases when demand begins to decrease with increasing penetration (i.e. the saturation effect dominates). The saturation effect in isolation indicates a higher price at any point in time than the corresponding myopic price, whereas the diffusion effect alone would indicate a lower price (to subsidize the early adopters and thereby stimulate the bandwagon effect for future profits).
- In the more realistic case of nonzero discount rate and cost-side learning, it is still optimal for prices to be increasing initially and then declining, as long as the diffusion effect is sufficiently strong and the discount rate is not too high. It pays to sacrifice early profits by subsidizing the early adopters, as long as the future is not discounted too heavily. Under a high discount rate and/or low diffusion effect, the optimal price path declines monotonically.
- In the case of nondurables (no saturation), the diffusion effect would imply a low initial price, increasing over time. Cost-side learning would also imply a lower price relative to the myopic optimum (at any point in time), but with a decreasing trajectory. Thus, with both diffusion and cost-side learning, the dynamic optimum price would be lower than the myopic optimum because both effects encourage stimulating sales now to drive up future demand and drive down future cost.
- In a trial/repeat model for nondurables, the optimal price declines (increases) monotonically if the decline in trial due to saturation is greater (lower) than the growth in repeat sales.

Multiplicative price influence on exogenous life cycle The general demand specification is

$$dN/dt = g(t) \cdot h(p(t)) \quad (9.5)$$

where $g(t)$ represents an exogenous life cycle, such as that generated by solving the Bass model (2) (Bass, 1980). Bass and Bultez (1982; Table 9.2(4)) and Kalish (1983) analyze this model, and find that the optimal price declines monotonically if there is cost-side learning. In this case, subsidizing early adopters does not help, since the exogenous life cycle specification does not incorporate the dynamic effect of price on demand as fully as the specification in (9.4).

Market potential as a function of price The demand model is of the general form:

$$dN/dt = f(N(t)) [\bar{N}(p(t)) - N(t)] \quad (9.6)$$

where the market potential \bar{N} is now modeled as a decreasing function of price and $f(N(t))$ represents the diffusion effect [$p + q[N(t)/\bar{N}]$]. Kalish (1983) examines this demand function as well, and shows that this case implies an initially increasing optimal price if the diffusion effect is sufficiently strong – qualitatively similar to the case of the multiplicative specification (9.4) discussed earlier. However, the condition for an increasing price trajectory is stronger, so that increasing prices will be less prevalent in this case

and, where they do occur, brief in their duration. Intuitively, increasing prices will have an adverse impact on the size of the potential adopter population, which is not an issue in the multiplicative price influence demand model.

The generalized Bass model (GBM) Bass et al. (1994) propose the generalized Bass model (GBM) in which $f(N(t))$ is given by the Bass (1969) model but $h(p(t))$ is replaced by a more general function that the authors term 'current marketing effort'. GBM models the effect of price differently from other multiplicative price influence models.

Krishnan et al. (1999; Table 9.2(5)) employ a slightly modified form of GBM to derive the optimal pricing strategy for new products, with the following current marketing effort function in place of $h(p(t))$ in (9.4):

$$x(t) = 1 + \gamma \ln p(0) + \beta \frac{dp(t)}{p(t)} \quad (9.7)$$

where γ and β are both negative. Note that this specification models the impact of the absolute level as well as the slope of the price path on demand.³ Under this formulation, the combination (actually, the product) of the diffusion price sensitivity parameter ($-\beta$) and the discount rate drives the optimal price path. If this combined effect is sufficiently small, the optimal price path is initially increasing and then declining; otherwise the path declines monotonically, as is often observed for many durables. In the multiplicative price influence models discussed earlier (Dolan and Jeuland, 1981; Kalish, 1983; Robinson and Lakhani, 1975), the price dynamics are driven by the demand dynamics (diffusion versus saturation), along with the discount rate and experience curve effects. In contrast, in the GBM formulation, the drivers are the diffusion price sensitivity and the discount rate (acting multiplicatively) and experience curve effects.

Incorporating demand uncertainty The models discussed above assume that demand is known with certainty over the entire planning horizon; realistically, firms launching new products are uncertain about demand over time. We review two models that explicitly incorporate different types of demand uncertainty. Chen and Jain (1992; Table 9.2(6)) consider uncertainty in the form of discrete shocks or 'jumps'. Raman and Chatterjee (1995; Table 2(7)) focus on demand uncertainty due to imperfect knowledge of the precise impact of explanatory variables included in the model as well as the 'random' impact of excluded variables.

Chen and Jain (1992) extend Kalish's (1983) deterministic model by including random shocks influencing demand. Their occurrence is governed by a Poisson process. Examples of such shocks are sudden changes to the potential market size or in economic conditions. The essential implications of Chen and Jain's analysis are:

³ While Krishnan et al. do not provide a behavioral justification for this specification, consideration of future expectations might suggest the inclusion of the price slope. However, the expectations argument would imply a positive sign for β .

- The impact of uncertainty on pricing policy increases the probability of the occurrence of the event and the magnitude of its after-effect.
- The impact of uncertainty can either reinforce or counterbalance the deterministic dynamic effects (as in Kalish, 1983), depending on whether the ‘contingent experience effect’ – the expected effect of cumulative sales on profits via its influence on the variation in the contingent state – is in the same or opposite direction as the deterministic experience effect.
- The price path experiences a jump at the time of occurrence of the contingent event.

Raman and Chatterjee (1995) incorporate the effect of demand uncertainty by allowing demand to be subject to stochastic disturbance. They find that, in general, the extent of impact of demand uncertainty on the optimal pricing policy is determined by the interaction among demand uncertainty, demand dynamics (diffusion and/or saturation effects), cost-side learning and the discount rate. For a Bass-type demand model with diffusion and saturation effects, they find (relative to the monotonically declining price path under deterministic demand in their infinite time horizon analysis) that:

- The effect of demand uncertainty is to (a) increase the initial price; (b) decrease the initial slope (that is, the price declines less steeply in cumulative sales); and (c) make the optimal price (both level and slope) less sensitive to changes in the discount rate or the coefficients of innovation and imitation that together determine the magnitude of demand dynamics.

Intuitively, uncertainty moderates the impact of the variables driving optimal price dynamics.

Incorporating the manufacturing–marketing interface In an interesting cross-functional modeling endeavor, Huang et al. (2007; Table 9.2(8)) develop a model that includes product reliability, Bass-type demand-side dynamics and cost-learning effects. The decision variables are product reliability (at the design stage) and dynamic policies over the planning horizon with regard to (i) price and (ii) length of the warranty. Given the complexity of the model, general qualitative implications are difficult to articulate, although the authors identify the direction of the slopes of the price and warranty policy paths for different conditions relating to the current value Hamiltonian and demand dynamics (diffusion versus saturation). Further, they provide numerical examples to demonstrate how dynamic programming may be employed to derive optimal policy. For a particular set of parameter values, it is shown that both optimal price and warranty period decline over time. This model represents a valuable (and rare) effort to capture the cross-functional aspects of decisions involving new products.

2.2 *Models considering the individual customer adoption decision*

The models discussed in Section 2.1 specify demand at the aggregate level, without really explicitly considering the customer adoption process. We next examine three models proposed by Jeuland (1981), Kalish (1985) and Horsky (1990) (Table 9.2(9), (10) and (11)) that extend the aggregate diffusion model paradigm to include aspects of the adoption process leading to an explicit adoption decision rule at the disaggregate level.

This provides potentially richer implications for new product pricing that augment the findings from the aggregate models. These models postulate that (a) the population is heterogeneous in their reservation price for the new product, (b) potential adopters are uncertain about its performance, lowering their reservation price, (c) information from adopters and other sources reduces this uncertainty, and (d) an individual adopts the product once its price falls below her reservation price.

Jeuland (1981) assumes that uncertain potential adopters believe that there is some probability that product performance will be lower than its true level. Once they are informed of the true performance (through word-of-mouth from adopters), their reservation price jumps up. The dynamics are thus driven by (a) the information diffusion process (which follows a process governed by the model (2) with the coefficient $p = 0$), and (b) the pricing policy. Qualitatively, the optimal pricing policy implications are similar to those for the aggregate-level multiplicative price influence models discussed earlier. However, the distribution of reservation prices across the population affects the specific trajectory of the optimal price path over time.

Kalish (1985) includes an explicit awareness component in his framework. At any point in time, individuals in the population belong to one of three stages: (a) unaware; (b) aware but yet to adopt; and (c) adopter. Awareness of the new product diffuses according to a model similar to (2), with the coefficient of innovation p a function of advertising, and word-of-mouth generated by both groups (b) and (c), with different coefficients of imitation q_1 and q_2 , respectively. Aware customers are still uncertain of their valuation; this uncertainty decreases as the number of adopters increases. Aware customers become potential adopters when their risk-adjusted valuations exceed the price. These potential adopters actually adopt the product gradually after this adoption condition is met, with a constant conditional likelihood of adoption (hazard rate). The implications of Kalish's model for durable and nondurable goods are as follows:

- *Durable goods* The optimal price decreases monotonically, unless adopters are highly effective in generating awareness and/or early adopters reduce their uncertainty significantly. In the latter case, prices may increase at product introduction, when customers are the least well informed and the marginal value of information is the highest.
- *Nondurable goods* For constant marginal cost (i.e. no cost-side learning), the optimal price will increase to some steady-state level, if and only if advertising is decreasing, which is the case unless the discount rate is high.

These results for durable and nondurable goods are qualitatively consistent with the implications of the aggregate-level models, with the added insight into the role of uncertainty reduction.

Horsky (1990) uses a household production framework to show that individual (or household) reservation prices depend on product benefits and wage rates. Assuming an extreme value distribution for the wage rate across the population yields a logistic adoption function, dependent on the wage rate distribution parameters and the price. These 'eligible adopters' may delay their purchase because of unawareness, product performance uncertainty, or expectations of a price decline, all of which are assumed to decrease in cumulative sales. The resulting diffusion model reduces to the 'market potential as a

function of price' form in (9.6), with the eligible adopters (obtained from the logistical adopter model) as the potential adopters.

Given the model set-up, the results are consistent with those of the aggregate-level 'market potential as a function of price' model (Kalish, 1983). If the diffusion effect is weak, the optimal price path declines monotonically. If it is sufficiently strong, then prices start lower to subsidize the early adopters and rise before declining. If the effect is especially strong, the initial price may actually be lower than the initial marginal cost, implying negative early contribution.

In summary, the pricing implications of these three models are broadly consistent with the aggregate-level diffusion models discussed in Section 2.1. However, they add nuances to the implications by virtue of their disaggregate-level behavioral assumptions – in particular, the distribution of reservation prices (wage rates in Horsky's model) in the population influences the price trajectory. While these models consider the individual-level adoption decision and thereby incorporate heterogeneity, the dynamics of demand are largely driven by the model components (e.g. awareness) based on an aggregate diffusion model specification, e.g. Bass (1969).

2.3 Models incorporating strategic customers with future expectations

With time-varying price paths, customers may form expectations of future prices (or product performance) and take these future expectations into account while making their current purchase decisions. The models discussed so far effectively ignore the role of customer expectations, assuming that customers act myopically.⁴ We now examine models explicitly incorporating customer expectations. These models are commonly based on rational expectations – implying that, in equilibrium, customers correctly predict the pricing policy to be followed by the monopolist. While as a descriptive model of customer behavior the rational expectations assumption is perhaps unrealistic in terms of the implied customer sophistication, its use as a paramorphic ('as if') modeling device in predicting outcomes in dynamic economic systems (including a firm's pricing policy) is widely accepted.

Besanko and Winston (1990; Table 9.2(12)) show how customer foresight influences a durable goods monopolist's price-skimming strategy over multiple time periods. Customers are intertemporal utility maximizers with rational expectations and constant reservation prices that are uniformly distributed over the population. The subgame-perfect Nash equilibrium analysis compares the dynamic pricing implications in the case of rational customers (with perfect foresight) with that of myopic customers.⁵ The key findings are as follows:

⁴ Kalish (1985) and Horsky (1990) mention future expectations, but do not incorporate them formally in the model.

⁵ A subgame-perfect Nash equilibrium is a Nash equilibrium whose strategies represent a Nash equilibrium for each subgame within the larger game. Limiting the equilibrium to be subgame-perfect rules out unreasonable commitments by the firm (such as committing to not lowering prices in the future, when such lowering will always be profitable).

- The optimal pricing policy for a firm facing myopic customers declines monotonically. The price is higher than the single-period profit-maximizing price in each period except the last.
- The policy for a firm facing rational customers also declines monotonically. However, the price is lower than the single-period profit-maximizing price in each period except the last.
- For a given penetration level, optimal prices are always lower and their decline more gradual, for rational customers. The first-period price for myopic customers is higher, although at some point in time this price may drop below that for rational customers.
- Using a pricing policy that is optimal for myopic customers when the customers are actually rational leads to suboptimally high prices initially and lower profits overall.

Comparing the multi-period versus the single-period case, a higher price in any period but the last makes sense for myopic customers because the firm can sell to those who have not yet bought in a future period, at lower prices. However, with rational customers, this effect is more than offset by the greater price sensitivity of customers who are willing to wait for prices to drop if there are future periods. Thus, with myopic customers, a firm would prefer as many periods (or opportunities to drop its price) as possible within the overall time horizon, for more effective skimming. With rational customers, it is the opposite – a shorter time horizon, or fewer but longer periods within the horizon, is preferred. The challenge for the firm is to be able to credibly commit to holding prices constant over the longer time period.

Besanko and Winston's analysis provides important insights into the impact of customer foresight, in isolation from other dynamics such as positive network effects (which would imply that reservation prices increase with market penetration, rather than being constant).

Narasimhan (1989; Table 9.2(13)) incorporates rational customers along with diffusion effects, assuming two types of customers differing in their reservation prices. New customers enter the market in each period, with the number given by a Bass (1969) type diffusion model. Once they enter the market, customers exit only after making their purchase of the durable. The purchase decision is based on maximizing intertemporal surplus. The key results are as follows:

- The optimal price path follows a cyclical pattern. Over each such cycle, the price declines monotonically from a high level (to sell to the high-valuation customers) and ends at a low level (for one period) to sell to the accumulated stock of low-valuation customers before returning to the high level. Customer expectations limit the price decline within each cycle.
- The length of the price cycles and the depth of discount depend on the relative sizes and valuations of the two segments, and the diffusion model coefficients. A higher coefficient of imitation implies shorter cycles to profit from early market penetration.

While these cyclical pricing implications are interesting, it is not clear if the same effect will persist if the distribution of reservation prices is continuous (e.g. uniform) across the

potential adopters, rather than dichotomous, as assumed. Also, as Narasimhan points out, prices would decline monotonically without cycling if the high-valuation customers entered first, which seems more plausible than both customer types entering in a fixed ratio in each period.

Moorthy (1988; Table 9.2(14)) considers a two-period model with uniformly distributed reservation prices across customers. Customers are uncertain about the cost of the durable, and use the first-period price to form expectations of the second-period price. The question is: can a low-cost monopolist pretend to have a high cost and thereby charge a high price in the first period, before dropping prices in the second period to exploit its low costs? The analysis shows that this is not possible – the firm's optimal decision is to price such that it reveals its true cost in the first period. This result suggests some robustness to the implications of the rational expectations model: the firm cannot 'fool' the customers even if they do not know the product cost.

In a similar vein, Balachander and Srinivasan (1998; Table 9.2(15)) analyze a two-period model in which rational customers with uniformly distributed reservation prices are uncertain about the degree of the firm's cost-side learning (high or low). The first-period price serves as a signal for customers to update their beliefs. The analysis yields a separating equilibrium in which a slow learning firm credibly signals its cost structure by charging a higher first-period price than if customers were fully informed. The signal is credible because a fast learning firm would charge a lower price to benefit from the experience curve effect in the first period.

In contrast to the above models focusing on durables, Dhebar and Oren (1985; Table 2(16)) consider a networked service (such as telecom) where customers can choose to subscribe period by period, with no start-up or termination fee (so that price expectations are not a factor). The value of the service depends on the price (subscription rate) and the number of subscribers. The optimal price path increases monotonically over time, consistent with the results for nondurables in Sections 2.1 and 2.2. Further, by anticipating future network growth, customers lower the equilibrium price (for a given network size) and thereby enlarge the network. A lower discount rate also has the effect of lowering price and enlarging the network.

Dhebar and Oren (1986) extend their 1985 model to consider nonlinear pricing where customers decide on usage volume in addition to subscription. They show that a nonlinear price schedule, consisting of a subscription price and a volume-based usage charge, results in a larger equilibrium network and higher profits than under a policy in which all subscribers pay the same fixed fee irrespective of usage. Dhebar and Oren's research focuses on networked services, which includes an increasing range of applications in today's technology-driven environment.

Price as signal of quality Can price serve as a credible signal of quality when there is uncertainty about quality? Research in economics (e.g. Milgrom and Roberts, 1986; Bagwell and Riordan, 1991) has shown that a high-quality firm may signal its quality via a price higher than the full-information optimum, if the high-quality firm's cost is sufficiently higher than that of the low-cost firm. Judd and Riordan (1994; Table 9.2(17)) use a signal-extraction model of customer behavior to explore this issue in the absence of any cost difference between the low- and high-quality firms. Customers' beliefs about the value of the product depend on their individual experience with the product as well

as the inference drawn from the price. The former makes it harder for the firm to deceive the customer. The two-period analysis shows that:

- When customers, uncertain about product quality, form beliefs based on both their product experience and the price, the high-quality monopolist can signal quality by initially pricing above the full-information price even if the high- and low-quality products have the same cost. As consumer learning increases over time, prices decline toward the full-information level.
- Firms have an incentive to invest in temporary enhancement of quality initially, to influence customers' beliefs about quality for future benefit.

Zhao (2000; Table 9.2(18)) includes advertising as a decision variable in addition to price in a quality signaling modeling framework. Advertising serves not just as a signaling device (as in Milgrom and Roberts, 1986), but also as a generator of awareness. The analysis shows that a high-quality firm will price higher and spend less on advertising when customers are uncertain about quality than in the full-information situation. Thus, high price signals high quality in this case, as it does in the price-only models. In contrast to the situation where advertising's only role is to signal quality, it is optimal to spend less on advertising when it also creates awareness.

2.4 Models incorporating successive generations of new products

We next review models focusing on successive generations of a product, where the next generation is an advanced version of the current one, and gradually replaces the latter.

Aggregate-level diffusion models Bayus (1992; Table 9.2(19)) models the sales of a next-generation durable considering the replacement behavior of the previous generation. The time horizon begins with the introduction of the second generation (G2). At the start, there is a fixed population of owners of the first generation (G1). At any point, some proportion of the installed base of G1 will require to be replaced. These 'normal' replacements may be sourced from either G1 or G2. In addition, the rest of the installed base is susceptible to making 'discretionary' (accelerated) replacements on account of the availability of G2 – these sales are influenced by the diffusion effect. Mathematically, sales of G2 are given by:

$$dN(t)/dt = [\bar{N} - N(t)] \{ [1 - \theta(p_1(t), t)]f(N(t))g(p_2(t)) + \theta(p_1(t), t)\varphi(p_1(t), p_2(t)) \} \tag{9.8}$$

where $N(t)$ is cumulative second-generation sales, \bar{N} is the initial market size (G1 installed base at the time of G2 introduction), $p_1(t)$ and $p_2(t)$ are G1 and G2 prices, respectively, $\theta(p_1(t), t)$ is the fraction of G1 installed base making 'normal' replacements at time t , $\varphi(p_1(t), p_2(t))$ is the fraction of 'normal' replacements sourced by G2, and $f(N(t))$ is the diffusion effect. Thus G1 sales equal $[\bar{N} - N(t)]\theta(p_1(t), t)[1 - \varphi(p_1(t), p_2(t))]$. The optimal G1 and G2 price paths can assume various patterns depending on specific conditions, indicating the complexity that consideration of successive generations with

overlapping sales adds to the pricing decision. However, for a sufficiently long planning horizon, the following results hold:

- The optimal price for G2 declines monotonically if G2 sales come from only ‘normal’ or both ‘normal’ and ‘discretionary’ replacements; or from only ‘discretionary’ replacements as long as the fraction of ‘normal’ replacements θ is sufficiently large. If θ is not large enough, the optimal price may be increasing initially. Thus the G2 price path declines when replacement is important (even without cost-side learning) because the initial G2 sales are sourced by G1 replacements and therefore no subsidization of early adopters is necessary.
- For a sufficiently large fraction of ‘normal’ replacement sales, the optimal price for G1 monotonically increases [decreases] if G2 sales come entirely from ‘discretionary’ (‘normal’) replacements. Thus the G1 price trajectory is heavily influenced by replacement behavior and the source of second-generation sales.

Bayus provides some empirical support for his results, using successive generations of different consumer durables (B&W/color TV; CD/LP record players; corded/cordless/cellular telephones).

Padmanabhan and Bass (1993; Table 9.2(20)) analyze a successive-generations model, with only the first generation (G1) available in the first part of the planning horizon, until the second (advanced) generation (G2) is introduced at some exogenously determined point. The demand specification is fairly general, in order to capture a variety of possible demand dynamics:

$$\text{G1: } dN_1(t)/dt = (1 - \theta)f(N_1)(t), p_1(t) \quad \text{and} \quad (9.9)$$

$$\text{G2: } dN_2(t)/dt = g(N_1(t), N_2(t), p_1(t), p_2(t)) \quad (9.10)$$

where $N_1(t)$, $N_2(t)$ are the cumulative sales of G1 and G2, $p_1(t)$, $p_2(t)$ are the G1 and G2 prices, and θ is the fraction of first-generation sales switching to the second generation ($\theta = 0$ prior to G2 introduction, and some constant value $0 < \theta < 1$ thereafter). Thus, after the introduction of G2, some (fixed) fraction of G1 sales is cannibalized by G2, which also generates sales from its independent market potential. The model may be viewed as a successive-generations extension to Kalish (1983), with the following implications:

- Prior to G2 entry, a positive impact of additional G1 sales on G2 demand (diffusion effect) reduces the G1 price. If the impact on G2 demand is negative (saturation effect), then the G1 price increases. Otherwise, the G1 price slope is in line with Kalish (1983).
- After G2 entry, a higher substitution rate θ drives the G1 price closer to, and the G2 price away from, their myopic optimal levels. Also, if G2 sales are increasing in the G1 price, the latter is higher to sell more of G2. However, a positive impact of G1 sales on G2 demand implies a lower G1 price to stimulate G1 sales. The net effect depends on the relative strengths of these factors. The G2 price trajectory is otherwise in line with Kalish (1983).

One interesting implication of both models is that it may sometimes be optimal to actually increase the price of the first-generation product after the introduction of the next generation: all else equal, a higher G1 price is likely to have a positive impact on G2 demand.

Successive generations and strategic customers with perfect foresight Since customers with perfect foresight can anticipate the introduction of a superior product, what are the implications for strategy? Using a two-period model, Dhebar (1994) shows that if the technology improves too rapidly (so that the product improves in ‘present value’ terms), there is no equilibrium because the monopolist has the incentive to target customers who did not buy in the first period with low second-period prices. High-end customers are tempted to wait for the improved product. Thus there is a demand-side constraint imposed on the rate of product improvement.

Kornish (2001; Table 9.2(21)) uses a two-period model similar to Dhebar’s, but assumes that if both generations were free, customers would be better off having G1 in period 1 and then switching to G2 in period 2 rather than waiting for G2. Under these assumptions, an equilibrium can exist if the successive generations imply improvement in ‘real value’ terms, as long as the monopolist does not offer a special upgrade price for G2 to current G1 owners. For the monopolist to credibly commit to such a single price in Period 2, he would need to make it impossible for a G1 owner to distinguish herself from a non-owner (e.g. by setting conditions that were either too difficult to prove, or too easy to claim, G1 ownership).

2.5 Normative models in a monopolistic setting: summary of implications

To conclude this section’s review of monopolistic models, we summarize the main (and robust) implications for new product pricing strategy from the literature. The dynamic optimum policy is contrasted with the short-term (myopic) optimum that ignores the future profit implications of current decisions. We focus on the effect of individual factors – typically, when several factors operate simultaneously, the net impact depends on their relative strength.

- *Cost-side learning* Experience curve effects lower the optimal price (at any point in time) relative to the myopic optimum, while the dynamic optimal price declines over time.
- *Demand-side learning (diffusion effect)* The diffusion effect lowers the optimal price relative to the myopic optimum; the dynamic optimal price increases over time.
- *Demand saturation (for durables)* Saturation increases the optimal price relative to the myopic optimum; the dynamic optimal price decreases over time.
- *Demand dynamics for durables* For durables, saturation becomes the dominant effect over time relative to diffusion, as the market saturates. If the diffusion effect is sufficiently strong, the optimal price starts low to subsidize early adopters, then increases before declining.
- *Nondurables: net impact of demand- and cost-side learning* The optimal price is lower at any point in time than the myopic optimum, while its slope depends on the strength of demand-side learning (from diffusion and/or learning-by-use) relative to cost-side learning.

- *Random demand shock* The likelihood of a random shock impacts the price path. The degree of impact depends on the probability of occurrence on the event and the magnitude of its after-effect. The price path itself will exhibit a jump at the time of the shock.
- *Demand uncertainty* The impact of demand uncertainty is to make the optimal price less sensitive to the demand dynamics relative to the deterministic case.
- *Customer heterogeneity in willingness to pay in a durable goods market: myopic customers* In the absence of other effects, the optimal price follows the classic skimming strategy, with prices starting high to target the high-valuation segment and then declining over time to target successively lower-valuation segments. In each period, the price is higher than the single-period optimum.
- *Customer heterogeneity in willingness to pay in a durable goods market: strategic customers with perfect foresight* In any period, the optimal price is lower than the single-period optimum if customers have perfect foresight. Relative to the strategy for myopic customers, the starting price is lower and the price decline is more gradual when customers are strategic.
- *Services with positive network effects* The optimal price of a networked service (such as telecom) is monotonically increasing over time. Anticipation of future network growth (by strategic customers) serves to lower the price for a given network size.
- *Signaling cost structure (durable goods)* If customers are uncertain about the firm's cost structure, the firm should set the first period price to reveal its true cost structure, rather than masquerading otherwise. Similarly, if the uncertainty is about the rate of experience-based cost reduction, it may be optimal for a firm with a low learning rate to signal this via an initial price that is higher than the full-information optimum.
- *Signaling by the firm under customer uncertainty about quality (nondurables)* A high-quality firm can signal quality by pricing higher than the full-information optimum. Prices decline over time (toward the full information price) with customer learning.
- *Successive generations (durable goods)*
 - The price of the second generation is more likely to be monotonically declining from the outset than for a single new product, because sales from replacement of the first generation reduce the need to subsidize early adopters.
 - The price of the first generation after introduction of the second generation depends heavily on replacement behavior and the source of second-generation sales.
 - The first-generation price prior to introduction of the second generation decreases (increases) if the impact of additional first-generation sales on the potential market for the second-generation is positive (negative).

3. Normative models in a competitive setting

The models reviewed in Section 2 assume the absence of competition, which may be reasonable for major innovations early in the life cycle, or else if the focus is at the industry level ignoring interfirm competition. The presence of competition, involving incumbent firms or potential entrants, can significantly influence new product pricing strategy.

Section 3.1 briefly introduces the methodology used to analyze competitive models. Section 3.2 reviews models that consider potential competition, with a firm enjoying monopoly status prior to competitive entry, while Section 3.3 reviews models incorporating competition among incumbent firms. Section 3.4 summarizes the strategic new product pricing implications in a competitive setting. Table 9.3 presents the key features and findings of selected competitive models.

3.1 *Equilibrium strategies in competitive situations*

In a competitive situation, a firm's performance and its best (profit-maximizing) decision is usually affected by the actions of the other competing firms. Analytical models typically employ a game-theoretic framework to obtain a non-cooperative Nash equilibrium solution, such that no firm has an incentive to unilaterally deviate from the equilibrium.⁶ As discussed earlier, the new product pricing decision should be in the form of a policy over time, considering the dynamic setting. The competitive counterpart to the optimal control formulation discussed in Section 2.1 is the differential game, which is employed to seek an equilibrium trajectory of the decision variable(s), where the objective of the firms is typically to maximize discounted profits over the planning horizon (Dolan et al., 1986; Dockner et al., 2000).

Two types of Nash equilibria are pertinent in the case of differential games. Open-loop equilibria express the policies as functions of time alone, while closed-loop equilibria are functions of time and the state of the system (e.g. cumulative sales). The strategies under the two equilibria are generally different, as illustrated later. Open-loop strategies are determined and committed to by the competitors at the outset for the entire planning horizon. Closed-loop policies capture the dynamics of competitive interaction by allowing strategies to adapt to the evolving state of the system over time. Closed-loop policies recognize that the best decision for a firm at any point in time is influenced by the positions (states) of its competitors, and are thus more appealing conceptually, though usually more difficult to derive analytically.

3.2 *Models considering potential competition*

Durable goods models with saturation effects We review two models that address the issue of potential competitive entry in a currently monopolistic market. Eliashberg and Jeuland (1986; Table 9.3(1)) analyze pricing strategies from the perspective of the first entrant, in a durable goods market. This firm enjoys monopoly status, until the second firm enters (at an exogenously specified point). Sales dynamics are driven by saturation effects alone and the price, with the following specification for the monopoly and duopoly periods:

$$\text{Monopoly: } dN_1(t)/dt = [\bar{N} - N_1(t)]\alpha_1[1 - kp_1(t)], \quad 0 < t \leq T_1 \quad (9.11)$$

⁶ This approach involves the specification of a particular form of firm conduct leading to competitive interaction. Studies in the new empirical industrial organization tradition instead estimate firm conduct rather than making an *a priori* assumption (see, e.g., Kadiyali et al., 1996 for a discussion of this approach).

Table 9.3 Normative models in a competitive setting

	(1) Eliashberg and Jeuland (1986)	(2) Padmanabhan and Bass (1993)	(3) Gabszewicz et al. (1992)	(4) Dockner and Jorgensen (1988)	(5) Rao and Bass (1985)
1. Product characteristics	Durable	Durable, successive generations of innovation introduced by different firms	Nondurable, experience goods for which consumers learn by using product (undifferentiated)	General model, but primary focus on durables	Dynamic industry price and market share paths in an undifferentiated oligopoly, with cost learning
2. Customer behavior/demand:					
(a) Demand drivers/sources of demand dynamics	Cumulative industry sales (saturation effect), own and cross price	1st gen: cumulative firm sales (saturation effect), own price; 2nd gen.: cumulative firm sales and own price, plus fraction of 1st gen. demand	Distribution of willingness to learn, prices	Cumulative firm/industry sales' prices (general specification of diffusion model; special cases analyzed)	Cumulative sales (diffusion and saturation effects), industry price
(b) Heterogeneity	No (aggregate-level specification)	No (aggregate-level specification)	Heterogeneity in willingness to learn (to use product)	No (aggregate-level specification)	No (aggregate-level specification)
(c) Uncertainty/learning?	No	No	Yes: learning through experience	No	Aggregate
(d) Strategic customers?	No	No	No	No	No

3. Firm/industry:							
(a) Experience curve effects?	No	No	No	Yes	Yes		
(b) Uncertainty/learning?	‘Surprised’ monopolist contrasted with correct anticipation of entry	No	No	No	No		
(c) Competitive setting	Monopoly period followed by duopoly	Monopoly period followed by duopoly	Monopoly period followed by duopoly	Oligopoly	Oligopoly		
(d) Decision variable(s)	Price	Price	Price	Price	Quantity		
(e) Type of equilibrium	Nash, open-loop	Nash, open-loop	Nash (Bertrand competition)	Nash, open-loop	Nash, open-loop		
4. Key results/pricing implications	<ul style="list-style-type: none"> • First entrant prices <i>drop</i> at point of follower’s entry • First entrant who correctly anticipates second entry (a) prices <i>higher</i> and decreases prices more gradually than if it were myopic, and (b) prices <i>lower</i> than if it did not anticipate the second entry 	<ul style="list-style-type: none"> • 1st gen. price <i>lower</i> than for integrated firm producing both generations in monopoly • 1st gen. price <i>drops</i> at 2nd gen. entry • After 2nd gen. entry, 1st gen. price <i>higher</i> than for integrated firm • 2nd gen. price <i>equal</i> to that for integrated firm 	<ul style="list-style-type: none"> • In case of brand-specific learning, pioneer prices <i>low</i> in monopoly period; both firms price <i>above</i> marginal cost in duopoly period • In case of category-level learning, pioneer chooses monopoly price in first period; both firms forced to price at marginal cost in second period 	<ul style="list-style-type: none"> • Prices may initially <i>increase</i> if diffusion effect is sufficiently strong, then <i>decrease</i> later • When demand is adversely affected by cumulative sales of competitors, change in slope of price path from positive to negative will tend to be <i>delayed</i> • Stronger impact of competition will <i>lower</i> prices 	<ul style="list-style-type: none"> • Industry prices will <i>increase</i> when diffusion effect is dominant and <i>decrease</i> when saturation effect is dominant • Lower-cost firm will have higher market share (with common industry prices) • Given cost-side learning, high-cost firm will produce more to reduce (or even reverse) cost disadvantage 		

Table 9.3 (continued)

	(6) Dockner and Gaundersdorfer (1996)	(7) Baldauf et al. (2000)	(8) Dockner and Fruchter (2004)	(9) Chatterjee and Crosbie (1999)	(10) Wernerfelt (1985)
1. Product characteristics	Durable goods (with demand governed by saturation effects)	Durable goods (with demand governed by saturation effects)	Durable goods (with demand governed by saturation effects)	Durable goods (of different quality across firms)	Nondurable, experience goods for which consumers learn by using product
2. Customer behavior/demand:					
(a) Demand drivers/sources of demand dynamics	Cumulative industry sales (saturation effect) and prices for both firms	Cumulative industry sales (saturation effect) and prices for both firms	Cumulative industry sales (saturation effect) and prices for both firms	Distribution of reservation prices, effect of customer foresight	Market shares of both firms, price difference (also informative and persuasive advertising in extended model)
(b) Heterogeneity	No (aggregate-level specification)	No (aggregate-level specification)	No (aggregate-level specification)	Yes – reservation prices	No (aggregate-level specification)
(c) Uncertainty/learning?	No	No	No	No	Yes – learning through experience
(d) Strategic customers?	No	No	No	Yes – perfect foresight	No
3. Firm/industry:					
(a) Experience curve effects?	No	No	No	No	Yes
(b) Uncertainty/learning?	No	Yes – 2nd period demand uncertain	No	No	No
(c) Competitive setting	Duopoly	Duopoly	Oligopoly	Duopoly	Duopoly
(d) Decision variable(s)	Price	Price	Price	Price	Price, also advertising
(e) Type of equilibrium	Nash, closed-loop	Nash, closed-loop (and open-loop)	Nash, closed-loop	Subgame-perfect (closed-loop)	Nash, open-loop

<p>4. Key results/pricing implications</p>	<ul style="list-style-type: none"> ● Closed-loop equilibrium price <i>higher</i> than myopic price; <i>drops</i> toward myopic price as discount rate increases ● Prices <i>decrease</i> as degree of competition between firms increases ● Prices under closed-loop strategies are <i>lower</i> than open-loop strategies. In both cases, prices <i>decline</i> over time and are <i>higher</i> than myopic prices ● When firms use debt financing, the 1st and 2nd period prices are <i>lower</i> and <i>higher</i>, respectively, relative to the no-debt case ● Closed-loop equilibrium prices are <i>declining</i> over time; higher the speed of diffusion, the <i>lower</i> the prices (in monopoly case, price independent of speed of diffusion) ● Prices <i>decrease</i> as number of firms in oligopoly increases ● Prices <i>decline</i> over time; customer foresight and competition both act to <i>lower</i> prices and <i>reduce</i> the rate of decline ● Superior performance provides firm with powerful competitive advantage in presence of customer foresight ● Over life cycle, prices generally first decline and then increase 				
<p>1. Product characteristics</p>	<p>(11) Wernerfelt (1986)</p> <p>Nondurable, experience goods for which consumers learn by using product</p>	<p>(12) Chintagunta et al. (1993)</p> <p>Nondurable, experience goods</p>	<p>(13) Chintagunta and Rao (1996)</p> <p>Nondurable, experience goods</p>	<p>(14) Bergemann and Välimäki (1997)</p> <p>Nondurable, experience goods – one established brand of known value and one new entrant of uncertain value</p>	<p>(15) Kalra et al. (1998)</p> <p>Nondurable, experience goods – one established brand of known quality and one new entrant of uncertain quality</p>
<p>2. Customer behavior/demand:</p> <p>(a) Demand drivers/sources of demand dynamics</p>	<p>Market shares, prices (general specification)</p>	<p>Customer preference, consumption experience, advertising, prices</p>	<p>Customer preference, consumption experience, advertising, prices</p>	<p>Distribution of customer valuations, prices</p>	<p>Distribution of customer valuations, prices</p>

Table 9.3 (continued)

	(11) Wernerfelt (1986)	(12) Chintagunta et al. (1993)	(13) Chintagunta and Rao (1996)	(14) Bergemann and Välimäki (1997)	(15) Kalra et al. (1998)
(b) Heterogeneity	No (aggregate-level specification)	Yes – preferences	Yes – price sensitivity (at segment level)	Yes – preference (Hotelling)	Yes – valuation of quality
(c) Uncertainty/learning?	Brand loyalty through experience	Preferences adjusted through consumption experience	Preferences adjusted through consumption experience	Yes – value of new brand	Yes – quality of new brand
(d) Strategic customers?	No	No	No	Yes	Yes
3. Firm/industry:					
(a) Experience curve effects?	Yes (on variable and fixed costs)	No	No	No	No
(b) Uncertainty/learning?	No	No	No	Yes – value of new brand (symmetric information between firms and customers)	No
(c) Competitive setting	Oligopoly	Duopoly	Duopoly	Duopoly, with one established and one new brand	Duopoly, with one established and one new brand
(d) Decision variable(s)	Price	Price, advertising	Price	Price	Price
(e) Type of equilibrium	Nash, open-loop	Nash open-loop	Nash open-loop	Markov-perfect equilibrium (closed-loop)	Sequential equilibrium

4. Key results/pricing implications
- Prices *decline* in presence of variable cost learning and *increase* over time in presence of demand-side learning (loyalty) and fixed-cost learning
 - For identical firms, prices *increase* over time (advertising declines)
 - If one firm enjoys higher consumer experience, other firm will price *lower* and advertise more to close gap
 - At steady state, the more preferred brand charges the *higher* price
 - The expected price path of new product *increases* over time, first at an increasing then at a decreasing rate
 - The expected price path of the incumbent *decreases* over time, first at a decreasing and then at an increasing rate
 - Under certain conditions, incumbent prices higher (than in full-information case) in first period before dropping prices in second period after entrant's quality is known
 - Entrant selects same initial price, whether high or low quality (signal-jamming equilibrium)
-

$$\text{Duopoly: } dN_1(t)/dt = [\bar{N} - (N_1(t) + N_2(t))] \alpha_1 [1 - k p_i(t) + \gamma (p_j(t) - p_i(t))],$$

$$i, j = 1, 2; j \neq i, T_1 < t \leq T_2 \quad (9.12)$$

where $N_i(t)$ and $p_i(t)$ are firm i 's cumulative sales and price at time t , and \bar{N} is the potential market size. The firms' objective is to maximize (undiscounted) profits over the entire planning horizon (including both monopoly and duopoly periods for the pioneer), assuming constant marginal cost (no cost-side learning). The open-loop equilibrium analysis shows that the prices for both firms decline monotonically, as expected, given that the dynamics are driven by saturation effects alone. The following results are interesting:

- In the presence of cross-price effects ($\gamma > 0$), there is a discrete drop in the pioneer's price at T_1 , when it loses its monopoly status; greater substitutability (larger γ) implies a larger drop.
- The monopolist who correctly anticipates entry at T_1 :
 - prices higher, and lowers prices less rapidly, than if he had been myopic because he accounts for the dynamic effects of saturation (greater current sales reduce future sales);
 - prices lower than if he (wrongly) assumes no competitive entry when setting its policy at $t = 0$, to reduce the potential market for the competitor via rapid market penetration.

Padmanabhan and Bass (1993; Table 9.3(2)) contrast the 'integrated monopolist' discussed in Section 2.4 with the case of separate firms introducing the first- and second-generation products (G1 and G2), for example, under technological leapfrogging by the second firm. The authors compare the pricing implications under the two scenarios (integrated and independent), using the following specific demand models in place of the more general forms (9.9) and (9.10):

$$\text{G1: } dN_1(t)/dt = (1 - \theta)(\bar{N}_1 - N_1(t)) \exp(-k_1 p_1(t)), \text{ and} \quad (9.13)$$

$$\text{G2: } dN_2(t)/dt = [\theta(\bar{N}_1 - N_1(t)) \exp(-k_1 p_1(t)) + (\bar{N}_2 - N_2(t))] \exp(-k_2 p_2(t)) \quad (9.14)$$

where, as before, $N_1(t), N_2(t)$ are the cumulative G1 and G2 sales, $p_1(t), p_2(t)$ are the G1 and G2 prices, and θ is the fraction of G1 sales switching to G2 ($\theta = 0$ before G2 introduction, and a constant thereafter). \bar{N}_1 and \bar{N}_2 are the market potentials for G1 and G2.

Note that the demand interrelationship between G1 and G2 in the second period is quite different from that between the competing products in Eliashberg and Jeuland's model, where the interrelationship is more symmetric, reflecting the different scenarios modeled. Padmanabhan and Bass focus on successive generations, with demand for G2 coming from cannibalization of G1 sales and from the independent potential market for G2. The demand for G1 is independent of the G2 price. However, like Eliashberg and Jeuland, Padmanabhan and Bass assume only saturation effects. Under these assumptions, the pricing implications for the independent (competitive) versus integrated cases are as follows:

- G1 and G2 prices decline monotonically over time in both integrated and independent cases, given that the demand dynamics are driven by saturation effects.
- Prior to G2 entry, the G1 price is lower at any point in time in the competitive case, since the first entrant prefers to reduce the potential G1 market remaining when G2 enters.
- At the time of G2's entry, the G1 price drops immediately in both cases.
- After G2's entry, the G1 price is higher in the competitive case, the opposite of the situation before G2 entry; in this model, the fraction of G1 sales cannibalized by G2 is a constant (θ).
- The G2 price is the same in both cases; the G1 price has no impact on the optimal G2 price.

Nondurable goods model In contrast to the above durable goods models with saturation driving demand dynamics, Gabszewicz et al. (1992; Table 9.3(3)) analyze a two-period model for a nondurable, with brand loyalty resulting from consumer learning-by-using. The products from the pioneer and follower are perfectly substitutable, although loyalty serves as a barrier to switching. Consumers are heterogeneous in their willingness to learn how to use the new product. The product must be consumed in the period purchased, and cannot be stored. At the end of the first period, those who bought the product have learned to use it. The authors compare the implications of two cases – brand-specific versus category-level learning:

- If the learning is brand specific, the pioneer uses a low introductory price in the monopoly period. In the second (duopoly) period, both brands price above marginal cost, despite being perfect substitutes; the pioneer brand has the higher price and the higher profits.
- If the learning is at the category level, the pioneer prices at the myopic monopoly price in Period 1 since there is no brand-specific advantage. Without brand loyalty, both firms are forced to price at marginal cost in Period 2, under Bertrand competition.

Thus brand-specific learning provides the pioneer with a first-mover advantage but also softens subsequent price competition via market segmentation, leaving even the follower better off than under category-level learning. The pioneer builds a sustainable competitive advantage via a loyal customer base by pricing low in the monopoly period. (In this model, the pioneer actually raises his price in the duopoly period over the monopoly period.)

3.3 Models incorporating competition against incumbent firms

Durable goods models: dynamics induced by diffusion and/or saturation effects Dockner and Jorgensen (1988; Table 9.3(4)) develop an oligopolistic extension of the Kalish (1983) model discussed in Section 2.1, starting with the following general demand model:

$$dN_i/dt = f_i(N_1(t), N_1(t), N_2(t), \dots, N_n(t); p_1(t), p_2(t), \dots, p_n(t)), i = 1, 2, \dots, n \quad (9.15)$$

where $N_i(t)$ and $p_i(t)$ are the cumulative sales and price for firm i , respectively. They analyze special cases of this general model. In general, the qualitative implications for price trajectories are consistent with the results in Kalish (1983). Case 1 considers price effects only, with dynamics only due to cost-side learning – with positive discount rates, optimal prices decline over time. Case 2 considers own and competitive prices as well as own cumulative sales N_i (but not cumulative industry sales), in a multiplicatively separable formulation:

$$dN_i/dt = f_i(N_i(t)) \cdot h_i(p_1(t), p_2(t), \dots, p_n(t)), \quad i = 1, 2, \dots, n \quad (9.16)$$

In this case, for a zero discount factor, equilibrium prices increase (decrease) over time if df_i/dN_i is positive (negative) for all i . As discussed earlier, df_i/dN_i is likely to be positive early in the life cycle (when the diffusion effect is dominant), and negative later when saturation drives the dynamics. Case 3 is similar to (9.16) except that demand is a function of cumulative industry sales $N = \sum_i N_i$ rather than firm-level cumulative sales N_i . Assuming a linear price effect, $h_i = a_i - b_i p_i + \sum_j \gamma_{ij}(p_i - p_j)$ and ignoring discounting and cost learning, equilibrium prices increase (decrease) over time if df_i/dN is positive (negative). Finally, Case 4 considers a duopoly, with demand a function of own and competitive cumulative sales but only own price:

$$dN_i/dt = f_i(N_i(t), N_j(t)) \cdot h_i(p_i(t)), \quad i, j = 1, 2; i \neq j \quad (9.17)$$

Again ignoring discounting and experience effects, equilibrium prices increase (decrease) over time if df_i/dN_i is positive (negative), though the change in slope of the price path (from positive to negative) occurs after the change in sign of df_i/dN_i (from positive to negative) if df_i/dN_j is nonzero. The intuition is that there is a greater incentive to penetrate the market to reduce the potential market for the competitors ($df_i/dN_j < 0$). In summary, the key implications of Dockner and Jorgensen's competitive extension of Kalish's (1983) model are as follows:

- Equilibrium prices tend to increase over time early in the life cycle when the effect of cumulative adopters on demand is positive. Later in the life cycle, equilibrium prices should tend to decline when the effect of cumulative adopters on demand is negative. This robust result holds across a variety of the competitive model variations considered, and is consistent with Kalish's results in the monopoly case.
- When a firm's demand is adversely affected by the cumulative sales of competing brands, the change in the slope of the price path from positive to negative will tend to be delayed.
- In general, the stronger the impact of competition (e.g. a larger cross-price effect on demand), the greater the downward pressure on prices.

In contrast to the models reviewed so far, Rao and Bass (1985; Table 9.3(5)) consider quantity (output) rather than price as the decision variable, in an undifferentiated oligopoly (so that there is a common industry price). The objective is to examine price and market share dynamics in the presence of demand- and cost-side dynamics. The common

industry price is a function of cumulative and current industry sales. The authors consider three special cases that isolate the three sources of dynamics in turn: saturation, diffusion and cost-side learning. While the industry price dynamics are in line with other models – price declines (increases) monotonically under a saturation (diffusion) effect alone, and also declines under cost-side learning alone – the analysis reveals interesting results for market share dynamics. Under demand-side dynamics (diffusion and saturation), a lower-cost firm will always have a higher market share than a higher-cost firm. Given cost-side learning, a higher-cost firm is more aggressive than a lower-cost firm in closing the gap in market share over time. Indeed, market share order reversals can occur in cases where the higher-cost firm might find it optimal to produce more than a lower-cost competitor.

Rao and Bass provide an empirical analysis of price dynamics in the semiconductor components industry that generally supports the theoretical results. The assumption of output as the decision variable in an undifferentiated market may be reasonable for industries with essentially commodity-type products (such as certain types of semiconductor components).

Models considering closed-loop equilibria Dockner and Gaundersdorfer (1996; Table 9.3(6)) analyze the properties of closed-loop equilibria for a durable goods duopoly market, considering saturation effects only and an infinite planning horizon. The closed-loop equilibrium price is higher than the myopic price, and drops toward the latter as the discount rate increases. Also, as expected, prices decrease as the products become more substitutable.⁷ However, the analysis does not compare open-loop and closed-loop strategies.

Baldauf et al. (2000; Table 9.3(7)) employ a two-period duopoly model with saturation effects to contrast open-loop and closed-loop strategies. They find that:

- When firms choose closed-loop strategies, optimal prices in each period are lower than corresponding open-loop prices. In both cases, prices decline over time and are higher in each period than the corresponding myopic prices.

Closed-loop strategies capture strategic competitive interaction, resulting, in this instance, in lower prices. Next, Baldauf et al. consider the implications of debt financing. Uncertainty is introduced in the second-period demand via a random disturbance term in market potential. The firms' objective is to maximize the expected equity value, concentrating on those states of nature in which there will be no bankruptcy. In this situation, long-term debt has a significant impact:

- When firms use debt financing, second period prices are higher (to avoid possible bankruptcy) while first period prices are lower (to compensate for higher second period prices) relative to their levels in the case of no debt financing.

⁷ The degree of substitution is captured by the γ parameter, as in Eliashberg and Jeuland (1986) – see (9.14).

Dockner and Fruchter (2004; Table 9.3(8)) investigate the combined effect of the speed of diffusion and competition, using the following demand specification:⁸

$$dN_i(t)/dt = \left[\bar{N} - \sum_{i=1}^n N_i(t) \right] \left[a - bp_i(t) + \gamma \sum_{\substack{j=1 \\ j \neq i}}^n (p_j(t) - p_i(t)) \right], i = 1, \dots, n \quad (9.18)$$

where the notations are as defined earlier. The speed of diffusion is defined as the percentage increase in the number of adopters corresponding to a 1 percent decrease in the time remaining in the product life cycle (an elasticity-like measure). The key implications are:

- Equilibrium prices decline over time. Given competition, the higher the speed of diffusion (i.e. shorter the life cycle), the lower the prices. In contrast, in a monopoly, the optimal price path is independent of the speed of diffusion.
- The prices decrease as the number of competitors in the oligopoly increases.

Models considering strategic customers with price expectations Chatterjee and Crosbie (1999; Table 9.3(9)) extend Besanko and Winston's (1990) model, discussed in Section 2.3, to a duopoly market, in which firms may sell products differentiated by quality. Customers are rational, with perfect foresight, and heterogeneous in their reservation prices. A subgame-perfect (closed-loop) equilibrium is sought in a discrete time framework. The results, derived partly analytically and partly via numerical simulation, have the following policy implications:

- Equilibrium prices decline over time as customers adopt the durable and leave the market in descending order of their valuations. Customer foresight and competition both lower prices and flatten the declining price path.
- Superior quality can provide a firm with a powerful, even dominant, competitive advantage relative to the case of myopic customers. A strong quality advantage can counteract a competitor's potential advantage from early brand introduction or lower marginal cost.

Nondurable goods models We next review four models that focus on nondurable products for which there is demand-side learning on account of consumption experience. Wernerfelt (1985; Table 9.3(10)) investigates price and market share dynamics over the life cycle in a duopoly, given scale economies and cost-side learning. The demand-side dynamics are modeled as follows. First, the rate of change of market share is proportional to the market shares of the two brands, the price difference, and a term that declines over time to reflect increasing brand loyalty. Next, the rate of change of individual-level consumption decreases in both price and the current consumption level. Finally, a financial constraint is imposed, requiring that some fraction of the funding needed for growth must be generated internally (based on prescriptions from the Boston Consulting Group). Wernerfelt's open-loop equilibrium analysis shows that:

⁸ This model is a special form of Case 3 in Dockner and Jorgensen (1988), with dynamics from saturation effects.

- Prices first decline and then increase; the larger firm's market share first grows, then declines.

The implications for the slope of the price path over the life cycle are the opposite of those implied by Dockner and Jorgensen's (1988) durable goods model based on diffusion and saturation effects, given the very different demand dynamics in Wernerfelt's model for frequently purchased products. In the case of durables with a finite market, saturation eventually dominates demand-side learning, whereas in Wernerfelt's model, demand-side learning (lowering price sensitivity) continues to grow without the constraint of saturation.

Wernerfelt's (1986) model (Table 9.3(11)) focuses on the implications of experience curves and brand loyalty for pricing policy in an oligopoly. Both fixed and variable costs decline owing to learning and exogenous technical progress. As in Wernerfelt (1985), the market share dynamics depend on current shares, prices and brand loyalty. The implications are that prices should decrease over time if discount rates are high and exogenous declines in variable costs are steep, but increase if fixed costs decline with learning and consumers are brand loyal.

Chintagunta et al. (1993; Table 9.3(12)) analyze dynamic pricing and advertising strategies for a nondurable experience good in a duopoly. Individual-level consumer choice is based on an ideal point preference model. Brand share is obtained by aggregating over consumers, allowing for heterogeneity. Consumers learn about a brand with each successive purchase. The accumulated brand consumption experience obeys Nerlove and Arrow (1962):

$$dG_i(t)/dt = S_i(t) - \delta G_i(t), \quad G_i(0) = G_{i0}, \quad i = 1, 2 \quad (9.19)$$

where $G_i(t)$ and $S_i(t)$ are firm i 's stock of accumulated consumption experience (goodwill) and sales, and δ is the goodwill decay factor. A brand's perceptual location depends on the function of current advertising effort and the accumulated consumption experience, so that higher levels of either imply greater brand preference. The key results, derived via numerical simulation, are:

- If firms are identical, prices increase over time (while advertising decreases).
- If one firm enjoys higher initial consumption experience by being the incumbent, then the other firm will initially market more aggressively by pricing lower (and advertising higher) than the incumbent. Over time, the price and advertising levels for the two brands converge.

In a related paper, Chintagunta and Rao (1996; Table 9.3(13)) develop a duopoly model for nondurable experience goods, with aggregate-level preference evolving according to the Nerlove–Arrow model, similar to the accumulated consumption experience in Chintagunta et al. (1993). At steady state, the more preferred brand charges the higher price. The authors show that managers who are myopic or who ignore customer heterogeneity make suboptimal pricing decisions. An empirical example demonstrates how the model may be estimated (and steady-state price predictions obtained) from longitudinal purchase data.

Competition against an established nondurable Bergemann and Välimäki (1997; Table 9.3(14)) consider the case of a firm introducing a new, differentiated, product to a market for a nondurable experience good currently served by an established firm with a product whose performance is well known.⁹ However, the performance of the new product is initially uncertain to customers as well as to the firms. This uncertainty can be resolved only by learning through actual purchases of the second product. Beliefs of product performance are updated gradually in a Bayesian manner. The authors derive the Markov-perfect equilibrium¹⁰ of the infinite horizon differential game, with the following implications, if the new product is of truly high quality:

- The expected price path of the new product is strictly increasing over time, first at an increasing and then at a decreasing rate (i.e. in an S-shaped pattern), while that of the established product is strictly decreasing, first at a decreasing and then at an increasing rate.

The uncertainty serves to soften competition and increase profits. The incumbent actually values information on new product performance more than the entrant does. Since such information is only available from new product sales, the incentives produce the dynamics noted above.

Kalra et al. (1998; Table 9.3(15)) consider a somewhat similar scenario – an established incumbent and a new entrant whose product is of uncertain quality – to examine whether there is a rationale for the incumbent to react slowly to the entrant as often observed in practice, when the expected response (under full information) would be an immediate price cut. Consumers are initially uncertain about the entrant's quality, and the true quality is revealed over time. Unlike in Bergemann and Välimäki, both firms know the true quality. The analysis, using the sequential equilibrium concept (Krebs and Wilson, 1982) in a two-period model, shows that:

- There are conditions under which the incumbent prices higher than the full-information price to effectively jam the entrant's ability to signal quality via its price. In this signal-jamming equilibrium, the low-quality and high-quality entrants select the same price. The incumbent's price gradually declines to the full-information level as consumers learn about the entrant's true quality.

Thus, whereas a monopolist may use price as a signal of quality (see Section 2.3), a later entrant may not have the ability to do so because of signal-jamming by the incumbent. This is also consistent with the often-observed practice of a delayed or gradual incumbent response. Kalra et al. also provide experimental validity for the premise underlying their result.

⁹ For other work by the same authors examining implications for strategic pricing in the presence of two-sided learning, see Bergeman and Välimäki (1996, 2000).

¹⁰ See Maskin and Tirole (2001) for a discussion of Markov-perfect equilibrium.

3.4 Normative models in a competitive setting: summary of implications

We conclude this section by summarizing the main implications for new product pricing strategy in a competitive setting, relative to the implications in a monopolistic setting (Section 2.5).

- *General effect of competition* In general, the stronger the effect of competition (for example, a larger cross-price effect), the lower the prices, all else equal.
- *Anticipating entry in a durable goods market with saturation effect* Prior to the competitor's entry, the incumbent monopolist's optimal strategy is to price higher and then reduce prices less rapidly over time than the myopic optimum, but price lower than if he does not account for competitive entry. Also, at the point of entry, the incumbent's price drops, with the magnitude depending on the strength of the cross-price effect.
- *Anticipating entry in a nondurable goods market with learning-by-using* If the learning by customers is mainly brand-specific (rather than at the category level), the pioneer prices below the myopic monopoly price prior to the competitor's entry.
- *Durable goods oligopoly* When a firm's demand is adversely affected by the cumulative sales of competitors (owing to saturation), there is greater incentive to use penetration pricing early relative to the monopoly situation – thus early prices will be lower and the change of slope of the price path from positive to negative will be delayed.
- *Open-loop versus closed-loop strategies for durable goods market with saturation* When firms adapt to the evolving state of the system over the planning horizon rather than committing to their strategy at the start of the planning horizon, prices in each period are lower.
- *Strategic customers with perfect foresight in a durable goods market* Both customer foresight and competition lower prices and make the price decline more gradual.
- *Nondurable goods duopoly with learning-by-using* Prices may first decline and then increase, or else increase monotonically over time; if one firm enjoys greater consumption experience initially (e.g. as the incumbent), the other firm will be more aggressive in its marketing, including charging lower prices, to close the gap between the firms.
- *Competitive reaction to a new entrant when the entrant's quality is uncertain to customers* Under certain conditions, the incumbent prices higher than the full-information duopoly price to effectively prevent the entrant from signaling quality to uncertain customers.

4. Setting new product prices in practice

In this section, we briefly discuss some tools and approaches that managers may apply to determine actual pricing policy for new products. A more detailed review of this topic is beyond the scope of this chapter; related issues are covered elsewhere in this volume.

4.1 Conjoint-based methods

Conjoint analysis (Green and Srinivasan, 1978, 1990) provides a popular and widely used methodological tool for assessing customers' willingness to pay for (possibly hypothetical) new products (Jedidi and Zhang, 2002). In particular, conjoint-based methods

for optimal pricing (preferably as part of an overall optimization methodology including product design) have been developed and applied (Green et al., 1981; Kohli and Mahajan, 1991; see also Dolan and Simon, 1996).¹¹ For methodological approaches based on information directly obtained from customers (or from secondary data) to estimate new product demand as a function of price and other demand-drivers, we refer readers to the chapters in this volume on measurement of reservation prices at the disaggregate level (Jedidi and Jagpal, Chapter 2) and demand estimation at a more aggregate level (Liu et al., Chapter 3).

4.2 Field experimentation

In situations in which it is important to track demand dynamics over time, an extended field experiment allows for estimation of a demand model that comes close to capturing reality. An example of such research is the study by Danaher (2002) involving a field experiment to derive a revenue-maximizing pricing strategy for new subscription services (applied to cellular phone market). The study also provides measures of the impact of access and usage prices on volume of usage and customer retention. In the experiment, a panel of homes was recruited to try a new cellular phone service over a year-long period. Both access and usage prices were manipulated systematically across groups within the panel. The model for usage and attrition was developed to fit the data from the experiment while also having the flexibility to describe a subscription service market that is closer to reality than the market in the experiment. It generalizes Hausman and Wise (1979) to deal with bias in the case of attrition. Unobserved heterogeneity is accommodated by employing latent segments. The specification of the revenue (or, more generally, profit) surface as a function of access and usage prices allows for the search of the optimal access and usage price levels.

Danaher's research illustrates a useful practical approach to new product pricing, using experiments that run over a sufficient length of time with manipulation of prices to be able to estimate the key demand dynamics (in this case, usage rates and attrition), in a reasonably realistic setting. In terms of broader findings, the analysis shows that access price primarily affects retention, while usage price affects usage and has an indirect effect on retention via usage (lower usage results in higher attrition).

4.3 Expert opinion/managerial judgment

Clearly, the specific product-market situation will dictate the appropriate choice of methodology for new product pricing. For example, for the pharmaceuticals industry, Woodward et al. (1998) propose a judgment-based approach that solicits experts opinions about the new product's market share under different scenarios based on prices, promotional effort and clinical benefits (as a basis for the product's value proposition and differentiation). The procedure involves a meeting among experts. A spreadsheet-based model returns the profit-maximizing price, promotional effort and value proposition (market differentiation) for each expert and for the group as a whole. The extent of

¹¹ For the interested reader, Sawtooth Software's technical papers library provides a useful set of materials of all aspects of conjoint analysis (<http://www.sawtoothsoftware.com/education/techpap.shtml>).

disagreement among experts is used to estimate incremental profits from obtaining additional information, via (i) an additional clinical trial (to define a stronger value proposition, possibly by establishing a second clinical indication) and (ii) a demand survey (to better estimate potential sales at different price points).

In summary, customer measurement tools (such as conjoint analysis), experiments (preferably in field settings), and expert opinion/managerial judgment-based approaches (Little, 1970, 2004), have been – and can be – used, possibly in combination, to determine pricing policy for a new product.

5. Conclusion

This chapter has attempted to organize and review the literature on new product pricing, with a primary focus on normative models taking a dynamic perspective. Such a perspective is essential in the new product context, given the underlying demand- and supply-side dynamics and the need to take a long-term, strategic, view in setting pricing policy. Along with these dynamics, the high levels of uncertainty (for firms and customers alike) make the strategic new product pricing decision particularly complex and challenging. We have distilled from our review of normative models the key implications for new product pricing, under various situations. These implications are intended to provide (i) theoretical insights into the drivers of dynamic pricing policy for new products and services, (ii) directional guidance for new product pricing decisions in practice, and (iii) directions for empirical research to test these results.

Given the multiple sources of dynamics and uncertainty, normative models have typically focused on some subset of all the situational factors that might exist in practice, in order to be tractable. Isolating the different effects helps in understanding their individual impact on the price path. However, being abstractions of reality, these models are limited as practical tools for new product pricing. On the other hand, the new product pricing tools available, briefly discussed in Section 4, are primarily helpful for setting short-term prices rather than a dynamic long-term pricing policy, which is what managers really need. Our review and discussion suggests several areas that offer opportunities for future research. Some avenues are discussed below.

5.1 Normative models: possible extensions

Dynamic models incorporating future expectations, successive generations, and current and future competition Today's business environment – characterized by shorter product life cycles, rapidly evolving demand- and supply-side dynamics (including customer tastes, technology and competition), and increasingly sophisticated customers – poses a real challenge for modelers, who must focus on these key drivers simultaneously to obtain managerially relevant pricing implications. Even with better analytical tools, the tradeoff between analytical tractability and richness must be recognized. Numerical methods would typically need to be used in conjunction with analytical approaches in order to derive meaningful results in these circumstances.

Multiple decision variables It is clearly simplistic to focus on price alone as the decision variable. While some dynamic models include additional marketing variables (typically, advertising), real-world new product strategy involves decisions across

functional areas. In this regard, the model by Huang et al.(2007) reviewed in Section 2.1 represents an encouraging start, albeit in a monopolistic setting. Again, the tradeoff between tractability and richness (and the use of numerical methods) becomes a germane issue.

5.2 Decision support systems

As observed earlier, the existing tools to support new product pricing decisions are limited in their ability to provide recommendations on dynamic pricing policy. There is an opportunity for developing managerial decision support systems incorporating dynamic models that can be calibrated via managerial judgment, historical data on analogous products, experimentation, or (ideally) some combination thereof to provide dynamic pricing strategy recommendations.

5.3 Nontraditional pricing schemes and other recent advances in pricing

The unique characteristics of services has prompted pricing schemes that include advanced pricing, use-based pricing and pricing for yield management. These topics have received recent attention and are covered in chapters in this volume by Shoemaker and Mattila (Chapter 25) on services, Xie and Shugan (Chapter 21) on advanced pricing, Kimes (Chapter 22) on yield management, and Iyengar and Gupta (Chapter 16) on nonlinear pricing. Further, prompted in part by recent technological advances (including the advent of the Internet), customized pricing of goods and services is now a viable option, prompting increasing use of auctions (and reverse auctions), and pricing to maximize customer lifetime value. Again, these topics are discussed in chapters by Park and Wang (Chapter 19) on mechanisms facilitated by the Internet (including ‘name your own price’ and auctions) and Zhang (Chapter 14 on price customization).

While these newer pricing topics have generated considerable research interest, there has been little work so far in the context of new products. This is clearly an important and fertile area for research, considering the unique challenges posed by new products, as discussed.

5.4 Takeoff of really new products

An example of an interesting research issue in the new product pricing domain is Golder and Tellis’s (1997) study of takeoff in sales of new household consumer durables. The authors argue that the traditional new product diffusion models do not capture the reality of the abrupt sales ‘takeoff’ for major innovations, at which point sales jump fourfold (or greater). They find that, for 16 post-World War II consumer durable categories, the price at takeoff was 63 percent of the introductory price, on average; furthermore, the takeoff often occurs at specific price points, e.g. \$1000, \$500, or \$100. Also, not surprisingly, the time to takeoff has been decreasing, from 18 years for categories introduced before World War II to six years for those introduced afterwards.

The phenomenon of sales takeoff warrants further attention, given the increasing number of new product introductions, particularly in the technology sector. In particular, the role of strategic pricing (and psychologically important price points, as suggested by Golder and Tellis’s findings) in determining new product takeoff is a promising topic for research.

References

- Bagwell, K. and M.H. Riordan (1991), 'High and declining prices signal product quality', *American Economic Review*, **81** (1), 224–39.
- Balachander, S. and K. Srinivasan (1998), 'Modifying customer expectations of price decreases for a durable product', *Management Science*, **44** (6), 776–86.
- Baldauf, A., E.J. Dockner and H. Reisinger (2000), 'The effects of long-term debt on a firm's new product policy in duopolistic markets', *Journal of Business Research*, **50**, 201–7.
- Bass, F.M. (1969), 'A new product growth model for consumer durables', *Management Science*, **15** (1), 215–27.
- Bass, F.M. (1980), 'The relationship between diffusion, experience curves, and demand elasticities for consumer durable technological innovations', *Journal of Business*, **53**, 557–67.
- Bass, F.M. and A.V. Bultez (1982), 'A note on optimal strategic pricing of technological innovations', *Marketing Science*, **1** (4), 371–8.
- Bass, F.M., D.C. Jain and T.V. Krishnan (2000), 'Modeling the marketing-mix influence in new-product diffusion', in V. Mahajan, E. Muller and Y. Wind (eds), *New-Product Diffusion Models*, Boston, MA: Kluwer Academic Publishers, pp. 99–122.
- Bass, F.M., T.V. Krishnan and D.C. Jain (1994), 'Why the Bass model fits without decision variables', *Marketing Science*, **13** (Summer), 203–23.
- Bayus, B.L. (1992), 'The dynamic pricing of next generation consumer durables', *Marketing Science*, **11** (3), 251–65.
- Bergemann, D. and J. Välimäki (1996), 'Learning and strategic pricing', *Econometrica*, **5** (September), 1125–49.
- Bergemann, D. and J. Välimäki (1997), 'Market diffusion with two-sided learning', *RAND Journal of Economics*, **28** (4), 773–95.
- Bergemann, D. and J. Välimäki (2000), 'Experimentation in markets', *Review of Economic Studies*, **67** (2), 213–34.
- Besanko, D. and W.L. Winston (1990), 'Optimal price skimming by a monopolist facing rational consumers', *Management Science*, **56** (5), 555–67.
- Chatterjee, Rabikar and Peter Crosbie (1999), 'Dynamic pricing strategies and firm performance in a duopoly: the impact of buyer expectations', Working Paper, Katz Graduate School of Business, University of Pittsburgh, Pittsburgh, PA.
- Chatterjee, R., J. Eliashberg and V.R. Rao (2000), 'Dynamic models incorporating competition', in V. Mahajan, E. Muller and Y. Wind (eds), *New-Product Diffusion Models*, Boston, MA: Kluwer Academic Publishers, pp. 165–205.
- Chen, Y.-M. and D.C. Jain (1992), 'Dynamic monopoly pricing under a Poisson-type uncertain demand', *Journal of Business*, **65** (October), 593–614.
- Chintagunta, P.K. and V.R. Rao (1996), 'Pricing strategies in a dynamic duopoly: a differential game model', *Management Science*, **42** (November), 1501–14.
- Chintagunta, P.K., V.R. Rao and N.J. Vilcassim (1993), 'Equilibrium pricing and advertising strategies for nondurable experience products in a dynamic duopoly', *Managerial and Decision Economics*, **14**, 221–34.
- Danaher, P.J. (2002), 'Optimal pricing of new subscription services: analysis of a marketing experiment', *Marketing Science*, **21** (2), 119–38.
- Dean, J. (1950), 'Pricing policies for new products', reprinted in *Harvard Business Review*, **28** (November–December 1976), 141–53.
- Dean, J. (1969), 'Pricing pioneering products', *Journal of Industrial Economics*, **17** (3), 165–79.
- Dhebar, A. (1994), 'Durable goods monopolists, rational consumers, and improving products', *Marketing Science*, **13** (1), 100–120.
- Dhebar, A. and S.S. Oren (1985), 'Optimal dynamic pricing for expanding networks', *Marketing Science*, **4** (4), 336–51.
- Dhebar, A. and S.S. Oren (1986), 'Dynamic nonlinear pricing in networks with interdependent demand', *Operations Research*, **34** (3), 384–94.
- Dockner, E.J. and G.E. Fruchter (2004), 'Dynamic strategic pricing and the speed of diffusion', *Journal of Optimization Theory and Applications*, **123** (2), 331–48.
- Dockner, E.J. and A. Gaundersdorfer (1996), 'Strategic new product pricing when demand obeys saturation effects', *European Journal of Operational Research*, **90**, 589–98.
- Dockner, E.J. and S. Jorgensen (1988), 'Optimal pricing strategies for new products in dynamic oligopolies', *Marketing Science*, **7** (Fall), 315–34.
- Dockner, E.J., S. Jorgensen, N.V. Long and G. Sorger (2000), *Differential Games in Economics and Management Science*, Cambridge: Cambridge University Press.
- Dolan, R.J. and A.P. Jeuland (1981), 'Experience curve and dynamic demand models: implications for optimal pricing strategies', *Journal of Marketing*, **45**, 52–62.

- Dolan, R.J. and H. Simon (1996), *Power Pricing*, New York: The Free Press.
- Dolan, R.J., A.P. Jeuland and E. Muller (1986), 'Models of new product diffusion: extension to competition against existing and potential firms over time', in V. Mahajan and Y. Wind (eds), *Innovation Diffusion Models of New Product Acceptance*, Cambridge, MA: Ballinger Publishing Company, pp. 117–49.
- Eliashberg, J. and A.P. Jeuland (1986), 'The impact of competitive entry in developing markets upon dynamic pricing strategies', *Marketing Science*, **5** (Winter), 20–36.
- Gabszewicz, J., L. Pepall and J.-F. Thisse (1992), 'Sequential entry with brand loyalty caused by consumer learning-by-using', *Journal of Industrial Economics*, **40** (4), 397–416.
- Gijsbrechts, E. (1993), 'Pricing and pricing research in consumer marketing: some recent developments', *International Journal of Research in Marketing*, **10** (2), 115–51.
- Golder, P.N. and G.J. Tellis (1997), 'Will it ever fly? Modeling takeoff of really new consumer durables', *Marketing Science*, **16** (3), 256–70.
- Green, P.E. and V. Srinivasan (1990), 'Conjoint analysis in marketing: new developments with issues for research and practice', *Journal of Marketing*, **54** (3), 17–37.
- Green, P.E. and V. Srinivasan (1978), 'Conjoint analysis in consumer research: issues and outlook', *Journal of Consumer Research*, **5** (2), 103–23.
- Green, P.E., J.D. Carroll and S.M. Goldberg (1981), 'A general approach to product design optimization via conjoint analysis', *Journal of Marketing*, **5** (4), 3–19.
- Hausman, J.A. and D.A. Wise (1979), 'Attrition bias in experimental and panel data: the Gary income maintenance experiment', *Econometrica*, **47** (March), 455–73.
- Horsky, D. (1990), 'A diffusion model incorporating product benefits, price, income, and information', *Marketing Science*, **9** (4), 342–65.
- Huang, H.-Z., Z.-J. Liu and D.N.P. Murthy (2007), 'Optimal reliability. Warranty and price for new products', *IIE Transactions*, **39**, 819–27.
- Jedidi, K. and Z.J. Zhang (2002), 'Augmenting conjoint analysis to estimate consumer reservation price', *Management Science*, **48** (10), 1350–68.
- Jeuland, A.P. (1981), 'Parsimonious models of diffusion of innovation part B: incorporating the variable of price', Working Paper, University of Chicago Graduate School of Business.
- Jeuland, A.P. and R.J. Dolan (1982), 'An aspect of new product planning: dynamic pricing', *TIMS Studies in the Management Sciences*, **18**, 1–21.
- Judd, K.L. and M.H. Riordan (1994), 'Price and quality in a new product monopoly', *Review of Economic Studies*, **61**, 773–89.
- Kadiyali, V., N.J. Vilcassim and P.K. Chintagunta (1996), 'Empirical analysis of competitive product line pricing decisions: lead, follow, or move together?', *Journal of Business*, **69** (4), 459–87.
- Kalish, S. (1983), 'Monopolistic pricing with dynamic demand and production cost', *Marketing Science*, **2** (2), 135–59.
- Kalish, S. (1985), 'A new product adoption model with price, advertising, and uncertainty', *Management Science*, **31** (December), 1569–85.
- Kalish, S. (1988), 'Pricing new products from birth to decline: an expository review', in T. Devinney (ed.), *Issues in Pricing: Theory and Research*, Lexington, MA: Lexington Books, pp. 119–44.
- Kalish, S. and S.K. Sen (1986), 'Diffusion models and the marketing mix for single products', in V. Mahajan and Y. Wind (eds), *Innovation Diffusion Models of New Product Acceptance*, Cambridge, MA: Ballinger Publishing Company, pp. 87–116.
- Kalra, A., S. Rajiv and K. Srinivasan (1998), 'Response to competitive entry: a rationale for delayed defensive reaction', *Marketing Science*, **17** (4), 380–405.
- Kamien, M.I. and N.L. Schwartz (1991), *Dynamic Optimization: The Calculus of Variations and Optimal Control in Economics and Management*, 2nd edn, New York: Elsevier Science.
- Kohli, R. and V. Mahajan (1991), 'A reservation-price model for optimal pricing of multiattribute products in conjoint analysis', *Journal of Marketing Research*, **28** (3), 347–54.
- Kornish, L.J. (2001), 'Pricing for durable-goods monopolists under rapid sequential innovation', *Management Science*, **47** (11), 1552–61.
- Krebs, D.M. and R. Wilson (1982), 'Sequential equilibria', *Econometrica*, **50** (4), 863–94.
- Krishnan, T.V., Bass, F.M. and D.C. Jain (1999), 'Optimal pricing strategy for new products', *Management Science*, **45** (12), 1650–63.
- Little, J.D.C. (1970), 'Models and managers: the concept of a decision calculus', *Management Science*, **16** (8), B466–B485.
- Little, J.D.C. (2004), 'Comments on "Models and managers: the concept of a decision calculus"', *Management Science*, **50** (12), 1854–60.
- Lu, Z.J. and W.S. Comanor (1998), 'Strategic pricing of new pharmaceuticals', *Review of Economics and Statistics*, **80** (1), 108–18.

- Maskin, E. and J. Tirole (2001), 'Markov perfect equilibrium: 1. Observable actions', *Journal of Economic Theory*, **100**, 191–219.
- Milgrom, P. and D.J. Roberts (1986), 'Price and advertising signals of product quality', *Journal of Political Economy*, **94**, 796–821.
- Monroe, K.B. and A.J. Della Bitta (1978), 'Models for pricing decisions', *Journal of Marketing Research*, **15** (3), 413–28.
- Moorthy, K.S. (1988), 'Consumer expectations and the pricing of durables', in T. Devinney (ed.), *Issues in Pricing: Theory and Research*, Lexington, MA: Lexington Books, pp. 99–114.
- Narasimhan, C. (1989), 'Incorporating consumer price expectations in diffusion models', *Marketing Science*, **8** (4), 343–57.
- Nerlove, M. and K.J. Arrow (1962), 'Optimal advertising policy under dynamic conditions', *Econometrica*, **29**, 162–75.
- Noble, P.M. and T.S. Gruca (1999), 'Industrial pricing: theory and managerial practice', *Marketing Science*, **18** (3), 435–54.
- Padmanabhan, V. and F.M. Bass (1993), 'Optimal pricing of successive generations of product advances', *International Journal of Research in Marketing*, **10**, 185–207.
- Raman, K. and R. Chatterjee (1995), 'Optimal monopolist pricing under demand uncertainty in dynamic markets', *Management Science*, **41** (1), 144–62.
- Rao, V.R. (1984), 'Pricing research in marketing: the state of the art', *Journal of Business*, **57** (1), S39–S60.
- Rao, V.R. (1993), 'Pricing models in marketing', in *Handbooks in Operation Research and Management Science, Volume 5: Marketing*, Amsterdam: North-Holland, pp. 517–52.
- Rao, R.C. and F.M. Bass (1985), 'Competition, strategy, and price dynamics: a theoretical and empirical investigation', *Journal of Marketing Research*, **22** (August), 283–96.
- Robinson, B. and C. Lakhani (1975), 'Dynamic price models for new-product planning', *Management Science*, **21** (10), June, 1113–22.
- Rogers, E.M. (2003), *Diffusion of Innovations*, 5th edn, New York: Free Press.
- Rohlf, J.H. (2001), *Bandwagon Effects in High-Technology Industries*, Cambridge, MA: MIT Press.
- Wernerfelt, B. (1985), 'The dynamics of prices and market shares over the product life cycle', *Management Science*, **31** (August), 928–39.
- Wernerfelt, B. (1986), 'A special case of dynamic pricing policy', *Management Science*, **32** (December), 1562–6.
- Woodward, R.S., L. Amir, M.A. Schnitzler and D.C. Brennan (1998), 'A new product pricing model using intracorporate market perceptions to extract the value of addition information', *Pharmacoeconomics*, **14** (1), 71–7.
- Zhao, H. (2000), 'Raising awareness and signaling quality to uninformed consumers: price-advertising model', *Marketing Science*, **19** (4), 390–96.