



Literature survey: Mathematical models in the analysis of durable goods with emphasis on information systems and operations management issues

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ARTICLE INFO

Available online 25 January 2012

Keywords:
Durable goods
Literature survey

ABSTRACT

Durable goods account for a significant portion of the economy and have been of considerable interest to academic researchers, especially economists, over the last four decades. Given the importance of strategic issues concerning durable goods markets to IS and OM researchers, our objective is to present a broad perspective of the research in this field that can serve as a starting point for their modeling efforts when analyzing these markets. Due to the complexity of these markets and the strategic interlinkage of decisions over time, a careful examination of the models is essential for the proper understanding and interpretation of the results from the literature. This paper provides a macro perspective of the research problems, a simple integrative framework for modeling durable goods, an introduction to the models and solution concepts commonly used in the literature, and a discussion of the primary results in the context of their modeling choices. Potentially interesting directions for future IS and OM research in this area are also identified.

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1. Introduction

Many physical and information goods are not *consumed* during use, but rather endure to be used repeatedly over an extended period (e.g., cars, aircraft, consumer electronics, and software). These *durable goods* are often big-ticket items, requiring considerable investment from both consumers and producers. They constitute a significant part of the economy, with annual consumer expenditures exceeding \$1 trillion. Therefore, understanding the functioning of markets for these goods and the incentives and actions of players in related industries is important to managers, regulators, and consumers. Not surprisingly, these markets have been studied extensively by economists over the last four decades. However, it is only recently that Information Systems and Operations Management researchers have really started paying attention to the *durability* of goods, the strategic behavior of consumers, and the resulting effects on strategic issues of interest to OM and IS. This is partly due to the complex, multifaceted nature of the modeling and analysis of these markets, which addresses consumers, value chains, and regulators, in addition to the producers and the products themselves. Existing literature uses differing modeling assumptions, arriving at a variety of findings, sometimes seemingly contradictory. As the authors can attest from personal experience, this imposes a relatively large starting cost on those trying to understand this literature sufficiently to make, or evaluate, contributions to it.

Our primary goal in this paper is to provide an efficient entry point for IS and OM scholars wishing to do analytical research on durable goods. The “big-picture” is presented in the form of an influence diagram and a modeling framework that together explain how the different pieces are connected, and where a particular paper or research question fits. The presentation of the major themes and the various analytical approaches taken, along with an explication of sometimes seemingly contradictory results, should aid researchers new to durable goods to “hit the ground running.” We also present a concise, yet thorough, discussion of the major themes and approaches of particular interest to IS and OM researchers. We encourage scholars intending to do research on durable goods to read the entire paper. Those seeking a quick overview, say to review a paper on a related topic, can skip [Sections 4 and 5](#) which discuss modeling and focus on [Sections 6 and 7](#), which discuss the key strategic issues.

Durable goods raise many vital strategic questions for sellers, consumers, and regulators. The first set of questions relates to issues of pricing and timing: How does durability affect a seller's pricing choices? How do the sellers' choices affect the timing of consumers' purchases? The second set concerns the choice of durability by producers, or in the case of information goods, the choices that producers make with regard to upgrades or planned obsolescence. The third set of issues relates to the design and coordination of distribution and supply channels. This includes the consideration of selling and leasing strategies, management of secondary markets, and the asymmetric information issues that these markets often raise. These issues are discussed in detail in [Sections 6 and 7](#).

We start by presenting an influence diagram (Howard and Matheson [42]) that provides a high-level perspective of the decision

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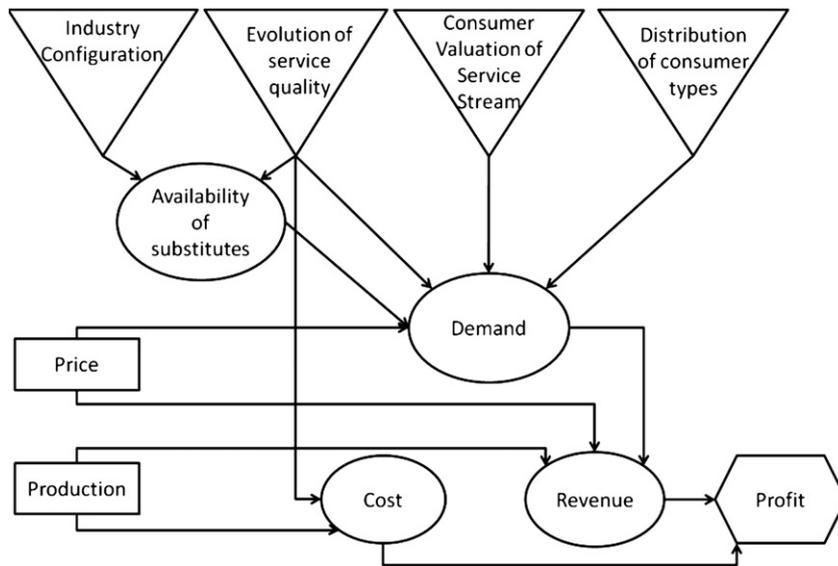


Fig. 1. Influence diagram to model manufacturer profit in production of durable goods.

problems that durable goods producers face (Fig. 1). These decisions are explored in detail in the rest of the paper. What the diagram makes particularly clear is that, in modeling demand, durable goods papers consider the influence of multiple factors. While we have depicted the most common assumptions about which variables are strategic (in boxes) and which ones are exogenous (in triangles), clearly other variations are possible. For example, the evolution of service quality could be a decision made by the manufacturer through his choice of durability.

While influence diagrams are useful for representing the key variables and their inter-relationships, they are poor at representing the dynamics of the problem. However, dynamic aspects are very important in modeling durable goods, since the temporal profile of the value provided to consumers and producers' decisions over time are interlinked. Nevertheless, Fig. 1 is a valuable tool for conceptualizing the set of relationships explored in a particular paper and identifying the assumptions made, explicitly or otherwise, about other potential variables. Thus it provides a framework for understanding the findings across different streams of literature and for coping with the seeming contradictions among them.

While researchers from a variety of disciplines are interested in durable goods, the kinds of questions they ask, and, to some extent, the analytical approaches they take, are quite different. Economists, who have done much of the seminal work in the area, are primarily concerned with descriptive models that explain observed market outcomes and with questions of economic efficiency. Economic efficiency, or social optimality, means that the overall welfare, as measured by the sum of the producer's profit and the consumer's surplus, is maximized. OM researchers focus largely on normative models related to manufacturers' decisions on production, capacity, inventory, and supply chains. New product introductions and the effect of digitization and the Internet on value chains have been the primary foci for IS researchers. Table 1 lists the primary research issues of interest to scholars in IS and OM and provides pointers to the sections in this paper that discuss the related literature and the relevant models, as well as providing links to salient references.

Given the size and diversity of the academic durable goods literature,¹ a comprehensive review is beyond the scope of this paper and

is also not consistent with our goal of providing an efficient entry point. Therefore instead of trying to be exhaustive, we have chosen papers based on their suitability at illustrating a particular modeling approach or explaining a particular strategic issue of interest to IS and OM audiences. Interested readers are referred to Waldman [76] and Orbach [58] for a more complete, non-mathematical review of the economic literature on durable goods.

Fig. 1 also previews the paper's structure, with most of the subsections examining one of the variables (either the exogenous parameters or the strategic variables) presented in the diagram. Section 3 provides an integrated framework that translates key aspects of Fig. 1 into a simple, dynamic analytical setting, which is expanded on in Sections 4 and 5. Section 4 discusses the different approaches to modeling the evolution of service quality, while Section 5 discusses the modeling of consumer value for service streams and the resulting demand. Understanding these modeling approaches is important to gaining insight into the results obtained in the literature. Sections 6 and 7 discuss key strategic decisions concerning durable goods sellers that are of particular interest to IS and OM audiences. We conclude in Section 8 with a discussion of potential research directions of interest to IS and OM. First, however in Section 2, we discuss time inconsistency, a problem related to the dynamic nature of durable goods decisions and a key theme in the literature.

Table 1
Primary research issues, pointers to sections, and key references.

Research Issues	Sections in the paper	Models in the paper	Key references
Time inconsistency	2	3.2, 3.3	[4,12,13,16,17,24,26,28,29,45,47,54,65,68]
Pricing	6.1	3.3	[8,29,31,45,46,57,68]
Choice of production technology	6.2	3.3	[47]
Durability, planned obsolescence, and upgrading	6.3	3.1, 3.3, 4.1, 4.3	[1,17,21,22,30,34,35,48,49,52,65,66,70,72,75]
Leasing versus selling	7.1	3.1, 3.2, 3.3, 5.1, 5.2	[9,11,12,15,16,25,32,41,43,44,64,73,74,78]
Complementary goods markets	7.2	4.2, 4.4, 5.1, 5.2	[9,19,20,38,54,66,70]
Secondary markets	7.3	5.1, 5.2	[2,3,5,36,60,77]
Channel design	7.4	5.1, 5.2	[4,10,26,62,63,71]

¹ There are about 7500 journal articles in JSTOR related to durable goods. A similar search on ProQuest found more than 5200 journal articles.

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