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Obsolescence of durable goods and optimal purchase timing

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ABSTRACT

We study a model with a durable good subject to periodic obsolescence and analytically characterize the optimal purchasing policy. The key result is that consumers optimally synchronize new purchases with the innovation cycle. The model simultaneously explains coordinated adoption without invoking network effects and provides a theoretical underpinning for a diffusion curve that features a temporary adoption slowdown.

1. Introduction

The arrival of better products at the same price is the major reason for depreciation in markets with technological innovation. Since much of this innovation is incorporated in new durables, modeling obsolescence of durable goods is vital for our understanding of technology adoption. Our goal is to characterize the aggregate demand for durables in a dynamic model of consumer choice that captures the essential distinctions between obsolescence and physical depreciation.

Obsolescence of a durable occurs with mere passage of time, typically because superior substitutes become available at the same price. By contrast, physical depreciation depends on utilization intensity (or the good's decay with physical age) specific to an individual unit. Thus, obsolescence and utilization are two distinct depreciation channels. Their aggregate effects are distinct, as well: while physical depreciation is idiosyncratic and its aggregate effects are likely smooth, obsolescence caused by innovation affects all durables within a market. Moreover, technological events that cause obsolescence may be predictable: major innovation episodes can be anticipated, especially when the introduction of new products is periodic. For some goods, such as automobiles, redesigned models do appear periodically, every 4 or 5 years. Even when obsolescence is not deterministic, obsolescence episodes are typically not independent events either. Innovation processes naturally have hazard rates that are negligible immediately after an innovation; after all, no one expects a new generation of products to appear immediately after the introduction of a new model. Therefore, we think that an innovation process with predictable, discrete jumps captures the main features of obsolescence that are distinct from physical depreciation.[1]

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[1] In reality, obsolescence patterns have both discrete and continuous elements, but markets in which discrete obsolescence is likely to be important are commonplace. The literature typically associates periodic obsolescence with a monopolistic producer whose timing of product introduction is a strategic

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Our analysis builds on the basic idea that consumer expectations about the timing of future innovations affect current purchasing behavior.[2] Suppose that individual units are expected to depreciate abruptly at some future date. Consumers who purchase their durables just before this date will enjoy a lower service flow than those who buy soon after. Hence, consumers have an incentive to buy a durable only when the design is sufficiently new and is not about to change soon. Thus, demand for new durables should drop some time prior to the dates when the new models become available. These anticipatory drops in demand have been noted for DVD players (Dranove and Gandal, 2003) and large-screen TVs (Shapiro and Varian, 1999, p. 15). In automobiles, regular timing of model year changes induces strong seasonal fluctuations in auto sales (Cooper and Haltiwanger, 1993a, 1993b).

We study an economy with a durable and a non-durable good and a large number of heterogeneous consumers. The durable good in our model represents a fairly narrow consumption category; hence, the assumption that innovation is periodic seems appropriate. Then, the non-durable category encompasses all options of deriving utility from expenditure outside of the durable market. The main feature that makes our framework distinct from a standard (s, S) model of durable replacement is the periodic (rather than continuous) arrival of better models of the durable. The periodic nature of model changes introduces a mixture of discrete (e.g., *whether* to buy the current model or wait for the next one) and continuous (e.g., *when* to buy the current model) choice variables and makes the replacement problem difficult to analyze. Nevertheless, we develop a special solution methodology that does not rely on marginal conditions and are able to solve analytically for the optimal consumption paths of individuals.

Our basic model features periodic innovation dates that are perfectly anticipated. One key property of the optimal solution is the no-delay result (Theorem 2): *all* consumers who purchase a particular model of the durable find it optimal to do so simultaneously, at the time when this model is first introduced. The timing of purchases depends on the interest rate and the (endogenous) marginal utility of wealth. If a consumer is buying the current model of the durable, and the interest rate is zero, then she is clearly better off buying without delay and getting the highest possible service flow from the new model. However, as the interest rate increases, consumers may prefer to buy in the middle of the design cycle, despite the loss of service flow. We show that purchasing a durable in the middle of the design cycle is never optimal because any consumer can be made better off by either buying the current model without delay or by buying some future model without delay.

Two unique implications derive from the no-delay result. First, it gives rise to a new mechanism for demand coordination that is not dependent on network effects, externalities or strategic complementarities. Previous literature that sought to understand simultaneous technology adoption stresses a different coordination mechanism based on positive externalities, such as information spillovers (Bannerjee, 1992), learning by doing (Jovanovic and Lach, 1989) and consumption externalities (Farrell and Saloner, 1985). The policy implications of the two mechanisms are distinct: adoption timing in our model is efficient, whereas in a setting with externalities, it is inefficiently slow.[3]

Second, the coordination mechanism that we identify in the basic model allows a more detailed understanding of empirical technology diffusion curves. The basic argument can be generalized to a setting in which model arrival dates are random, but the innovation hazard rate is negligible immediately after a new model introduction. When the hazard rate is initially negligible, consumers who purchase the durable early enjoy a longer time without obsolescence. Consumers then optimally separate themselves into two groups: early adopters, who act (almost) immediately, and late adopters, who choose to purchase the good with a long delay. Early adopters purchase the good at a higher price but are less exposed to the risk of obsolescence. By contrast, late adopters, who face a higher risk of obsolescence, find it optimal to wait until the price of the good falls. Since all consumers decide to act either early or late, no one purchases the good in the middle of its design cycle, and its diffusion curve reaches a temporary "plateau".[4]

Recent empirical results on diffusion curves are generally consistent with diffusion slowdown after the initial burst in demand. For example, Comin et al. (2006) outline the general characteristics of technology adoption patterns and conclude that "once the intensive margin is measured, technologies do not diffuse in a logistic way." In particular, for many technologies, a slowdown in the rate of diffusion follows the initial burst of adoption activity (see also Comin and Hobijn, 2010, Figs. 2, 3).

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variable (e.g., Swan, 1972; Rust, 1986; Fishman and Rob, 2000). Our focus is on a different set of markets, where major innovations affect all the producers, but they are infrequent due to technological constraints rather than strategic reasons. These markets include several (overlapping) categories. (1) Markets in which new products have a different format or standard. Format switching is typical for data recording or storage devices, such as disk drives, camcorders and digital cameras. (2) Goods that depend on a "bottleneck" (lagging) technology. For example, power supply has been a constraining factor in adding new features to many portable electronic devices. (3) Markets in which technological constraints are imposed by periodically changing government regulation, such as cellular communications.

[2] The idea of expectations-driven demand is similar in spirit to frameworks featuring deterministic output cycles: Shleifer (1986) and Francois and Lloyd-Ellis (2003) demonstrate how coordination of innovation dates across producers can arise from agents' rational expectations about the timing of economic booms and give rise to aggregate deterministic output cycles.

[3] As a specific example of a technology adoption subsidy, the Senate Commerce Committee approved a Digital TV bill that provided a $ 1.5 billion subsidy to consumers to facilitate the switch to HDTV (Source: US Senate Committee on Commerce, Science and Transportation Press release, Dec. 21, 2005). Our model suggests that some consumers were optimally waiting for the future generations of digital TV models, and the subsidy was not needed to incentivize them.

[4] Balcer and Lippman (1984) analyze the technology adoption problem under uncertainty with time-varying innovation arrival rate. They find that expected arrival of a better technology limits the total number of adopters, but makes them act fast. While our work shares a similar basic idea, we solve a more general (and a more challenging) problem with a budget constraint and highlight the features of the diffusion curve that are due to an uneven rate of obsolescence.