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Evolutionary model of an anonymous consumer durable market

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ABSTRACT

An analytic model is presented that considers the evolution of a market of durable goods. The model suggests that after introduction goods spread always according to a Bass diffusion. However, this phase will be followed by a diffusion process for durable consumer goods governed by a variation-selection-reproduction mechanism and the growth dynamics can be described by a replicator equation.

The theory suggests that products play the role of species in biological evolutionary models. It implies that the evolution of man-made products can be arranged into an evolutionary tree. The model suggests that each product can be characterized by its product fitness. The fitness space contains elements of both sites of the market, supply and demand. The unit sales of products with a higher product fitness compared to the mean fitness increase. Durables with a constant fitness advantage replace other goods according to a logistic law. The model predicts in particular that the mean price exhibits an exponential decrease over a long time period for durable goods. The evolutionary diffusion process is directly related to this price decline and is governed by Gompertz equation. Therefore it is denoted as Gompertz diffusion.

Describing the aggregate sales as the sum of first, multiple and replacement purchase the product life cycle can be derived. Replacement purchase causes periodic variations of the sales determined by the finite lifetime of the good (Juglar cycles). The model suggests that both, Bass- and Gompertz diffusion may contribute to the product life cycle of a consumer durable.

The theory contains the standard equilibrium view of a market as a special case. It depends on the time scale, whether an equilibrium or evolutionary description is more appropriate. The evolutionary framework is used to derive also the size, growth rate and price distribution of manufacturing business units. It predicts that the size distribution of the business units (products) is lognormal, while the growth rates exhibit a Laplace distribution. Large price deviations from the mean price are also governed by a Laplace distribution (fat tails). These results are in agreement with empirical findings. The explicit comparison of the time evolution of consumer durables with empirical investigations confirms the close relationship between price decline and Gompertz diffusion, while the product life cycle can be described qualitatively for a long time period.

1. Introduction

The evolutionary model presented here is based on the idea that durable goods produced for an anonymous market can be considered to be governed by the evolutionary Variation-Selection-Reproduction (VSR) mechanism, known form the evolution of species (for an overview [1,2]). For species the VSR-process can be summarized as follows:

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Species reproduce by creating offspring (R). During this reproduction process random mutations lead to a variation of the individuals (V). Selection operates whenever different types of individuals reproduce at different rates (S). The abundance of the fittest offspring is increased. The VSR-process therefore improves the overall fitness over a long time period.

We want to apply the idea of a preferential growth to durable goods. They are often produced for an anonymous market by different manufacturers. The goods differ slightly in their features. We want to denote these variants as models or products. Each model is manufactured by a business unit, while firms in general consist of a number of business units. Business units manufacture products, sell them to the market in order to manufacture more. For durable goods the VSR-mechanism can be considered as follows:

Business units reproduce the good (R). During the reproduction process they vary the features of the models (V). The preferences of potential consumers determine the selective "environment" and hence a part of the fitness space of a product. The fittest models have an evolutionary (competitive) advantage compared to other models. Their reproduction rate is increased due to an increased financial return (S). Since the models with the lowest fitness disappear from the market, the overall fitness will increase over a long time period.

An instructive example was given by Beinhocker [3], for the evolution of shirts. Shirts are manufactured by business units all over the world. Consumers have the choice between many different designs and prices. Some of the shirts are purchased more than others. The business units take advantage of this response and preferentially reproduce the best sellers. However, they also give designers the order to vary the best sellers. In the next generation non-best sellers disappear, while a number of variations exist for the best selling models. As a result, after sufficient time, the shirt market contains essentially shirts with the highest consumer preference.

The evolutionary theory presented below is based on this VSR-mechanism. However, it is much easer to vary the price instead creating permanently new versions of the product. The focus of the paper is rather on the impact of the price and the reproduction process on the market evolution, and does not explicitly consider the evolution of new models. Applying statistical methods a theory is developed that describes qualitatively the evolution of a durable consumer market over a long time period. However, in order to understand this process, we have to emphasize the difference between spreading and evolution.

Let us return first to a biological example. Suppose we consider a plant, stranded on an empty island. If it finds ideal conditions, the average plant density (plants per unit area) increases until its reproduction is limited by the size of the island. This process is a spreading process. It depends on the reproduction rate of the plant and the space left to populate. No adaptation of the plant occurs. Now suppose the same situation, where the island is not empty, but filled with other plant species. After stranding the spreading process starts until it saturates at a density that will be lower than in the case of an empty island. However, the plant has the opportunity to increase its population density by adapting to the biological environment formed by the other species. This can be done for example by symbiosis (cooperation) with other species or by replacing them. The process responsible for this adaptation process is evolution. Both processes, spreading and evolution lead to an increase of the plant density, while the spreading process is usually much faster than the evolutionary VSR-mechanism.

Let us apply this idea to a durable good manufactured for an anonymous market (e.g. TV sets, refrigerators, PC's etc.). The good plays the role of the species (plant) and the market corresponds to the island. The market penetration, which counts the number of adopters (users) of the product scaled by the target population, characterizes the evolution of the good. This penetration process is denoted in marketing as market diffusion [4]. After introduction, information about the product spreads by the word-of-mouth effect. Previous adopters inform their neighbors in the social network about the utility of the product. Those potential consumers, who can afford the product, will purchase the good during this spreading process. A model that describes this spreading was established by Bass [5]. Therefore we want to denote the corresponding spreading process as Bass diffusion. The spreading process increases the market penetration. However, during this process the features of the good remain constant.

The spreading process saturates after a sufficiently long time. For a low introduction price all potential consumers can purchase the good, (which corresponds to the empty island case). However, expensive consumer durables are not affordable for all potential consumers and the market penetration will saturate after Bass diffusion at a lower level (which corresponds to the filled island case). In this case the market penetration can be increased by a decrease of the product price. Due to preferred selection this variation leads to an increased return for the business units, and therefore to an increased reproduction rate of the favorable models. Because an increase of the market penetration can be interpreted as a diffusion process, there must be an additional diffusion process associated to the VSR-mechanism. In the presented evolutionary model the corresponding diffusion process can be described by a Gompertz equation and is therefore denoted as Gompertz diffusion. The Gompertz equation was originally developed in 1825 by the British actuary, Benjamin Gompertz, to describe the relationship between age and mortality [6,7]. The cumulative adoption curve is S-shaped, but unlike Bass penetration, the Gompertz curve is not symmetric. The highest rate of adoption occurs when around 37% of all eventual adopters have adopted.

A consequence of this evolutionary model is that both Bass and Gompertz diffusion may occur during the diffusion of an expensive consumer durable, while Bass diffusion takes place much faster. Gompertz diffusion must be directly related to a decreasing market price. As will be shown below, this prediction can be confirmed by empirical data.

Applying statistical methods the theory can be extended to establish a size and growth rate distribution of the business units (products), where the size is characterized by the unit sales. Also derived is the price distribution and mean price