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University of Nevada, Reno

Using Evolutionary Models of Choice with Consumer Theory Models of Substitute Goods

A thesis submitted in partial fulfillment
of the requirements for the degree of

Bachelor of Arts in Economics and the Honors Program

by
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Dr. Mark Pingle, Thesis Advisor

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Abstract

This research presents two evolutionary models of behavior and applies them to basic consumer theory in economics; that is, this research uses modeling concepts involving choice and behavior from various disciplines (most notably behavioral psychology) and reconciles them with consumer decision theory in economics. The economic assumption of the consumer—where they have “perfect information” about which product will provide the most satisfaction—is clearly counterintuitive; we, as consumers, are often unsure of which choice is best for us. The question, then, is “*How do consumers really choose the products that they do, and does this behavior tends to promote long-run optimal behavior?*” The question will be answered by referring to two models of evolutionary social learning, which attempt to model the decision-making process between two goods that are either perfect substitutes or imperfect substitutes of one another. By helping to answer this question through an examination of both models and a discussion of previous studies and findings in decision theory, this research provides a better understanding of the consumer—one that the “perfect information” assumption precludes.

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1. Introduction

Rationality, as the word is used in the rational choice theory of economics, is different from the standard use of the word. People generally think of rationality as sanity or level-headedness. Economics repurposes the word rationality to mean a comparison of all alternatives and subsequently choosing the best alternative. Interestingly, such rationality may include lying, cheating, and procrastination.

Of course, this view of decision-making may be overly simplistic. In real life, a consumer is typically not totally aware of his preferences, may not have full information about the prices of different alternative products, and may not be aware of his or her own income constraints.

The primary issue we consider here is not a preference or information issue, but rather is that sorting through a set of alternatives may have a deliberation cost that is so great that it is not reasonable to compare all alternatives. The fact that such deliberation costs exist in the decision-making process begs the question, “How do consumers decide to choose what they do?”

Rather than consciously sorting through alternatives, one way people respond to deliberation costs is to make a choice without comparing alternatives and then adapt that choice over time. The use of adaptive, evolutionary decision approaches can be explained by the fact that decision-makers economize on deliberation costs. Of course, without comparing alternatives, the choice at any given time will not be optimal. However, choices made adaptively can approach an optimum over time, especially if the environment is stable.

Adaptive strategies are roughly equivalent to learning approaches (McElreath et al, 2008), often described as rules of thumb. An optimal choice can be approached over time using individual learning, social learning or a hybrid of the two. All such learning strategies will be suboptimal in the short-run and require a stable long-run environment in order to approach optimality. However, because the strategies greatly reduce the cognitive complexity of decisions, there is the potential of being useful.

The approach here is to construct evolutionary models of consumer choice that relate directly to standard economic choice theory. The simplest choice situation involves choosing between two alternative goods. Within this simple two good context, two evolutionary models are constructed. As discussed in introductory microeconomic textbooks, such as Ahlersten (2009), the substitutability of goods is an important issue. It turns out that the case where two goods are perfect substitutes allows a simpler evolutionary model to be constructed because the optimal choice involves putting all income into only one of the two goods. In the real world, however, it is not typically true that any two goods are perfect substitutes. Constructing an evolutionary model for this more important general case is more difficult, but the second model presented here is an attempt at creating such an evolutionary model.

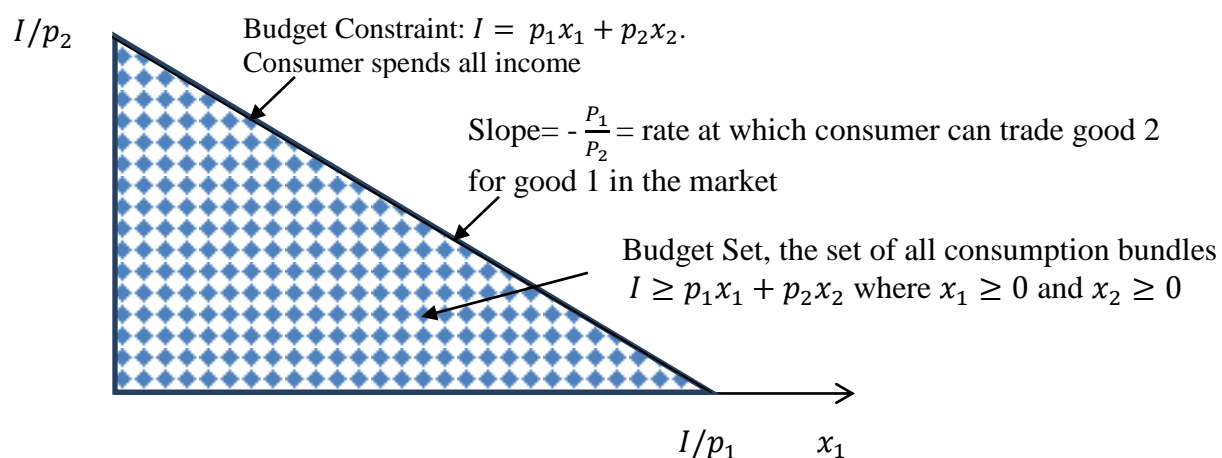
This thesis proceeds as follows: Section 2 provides the standard choice theory of economics; Section 3 provides an overview of background research relating to evolutionary models of learning and consumer theory. Section 4 describes perfect substitutes; Section 5 offering a model for consumer decision-making in the perfect substitutes context. Section 6 describes imperfect substitutes; Section 7 provides

modeling for decision-making in the imperfect substitute context; Section 8, the conclusion, discusses the findings and implications of the research.

2. Standard Choice Theory in Economics

In economics, it is standard to represent choice as the selection of the best alternative from a set of alternatives. For a consumer, the set of alternatives is constrained by the consumer's income. To be precise, consider a consumer with income I , who can choose to buy amounts x_1 and x_2 of goods 1 and 2 at prices p_1 and p_2 . The budget set is the set of alternative consumption bundles the consumer can purchase with income I . Specifically, the budget set includes the bundles (x_1, x_2) that satisfy the income constraint $p_1x_1 + p_2x_2 \leq I$. The budget set for the consumer is shown in Figure 1. The budget constraint, also called the budget line, is the set of alternative consumption bundles that exhaust the consumer's income, so $p_1x_1 + p_2x_2 = I$.

Figure 1: Consumer Budget Set



The slope of the budget line is $-P_1/P_2$, which is the rate at which the consumer can trade away good 2 for good 1 in the market. For example, if $P_1 = 4$ and $P_2 = -2$, so

$-P_1/P_2, = -2$, the consumer can buy one extra unit of good 1 by shifting income from good 2 such that 2 units less of good 2 are consumed.

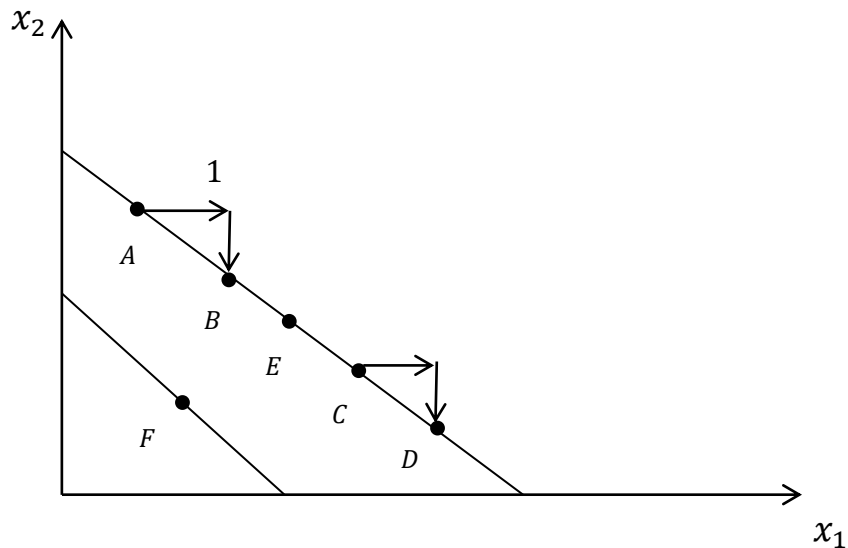
Given a budget set of alternatives, the consumer's preferences then determine the consumer's behavior or choice. It can be shown that, if a consumer's preferences satisfy certain reasonable assumptions,¹ then the consumer's preferences can be represented by a utility function. In general, the utility function $U = U(x_1, x_2)$ gives the level of satisfaction obtained from consuming levels x_1 and x_2 of goods 1 and 2.

An indifference curve is a tool that can be used to represent consumer preferences. A single indifference curve contains a set of consumption bundles that all yield the same level of utility or satisfaction. An indifference mapping, which is a set of indifference curves, can usually provide all the information needed about consumer preferences for the purposes of standard choice theory

Figures 2 and 3 present indifference curve mappings for the two preference cases considered in this thesis. The preferences shown in Figure 2 indicate the consumer finds good 1 and 2 to be perfect substitutes, while the preferences shown in Figure 3 indicate the consumer finds goods 1 and 2 to be imperfect substitutes.

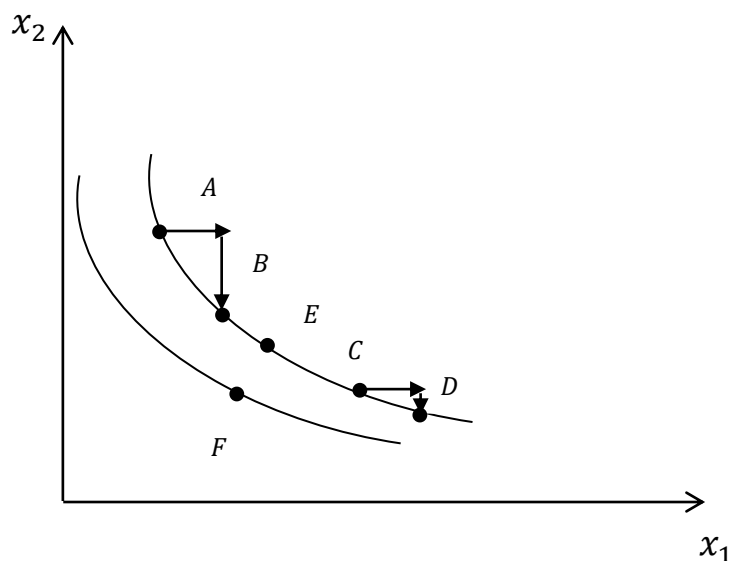
¹ An example of one assumption is transitivity. A consumer's preferences are transitive if, preferring bundle A to bundle B and preferring bundle B to bundle C, the consumer prefers bundle A to bundle C.

Figure 2: Perfect Substitute Preferences



The points shown in Figure 2 allow the perfect substitute preferences to be explained. If the consumer shifts from point A to point B, one extra unit of good 1 is obtained. The same is true with a shift from point C to point D. Notice that the decrease in good 2 necessary to return to the indifference curve is the same with each shift. The constant rate indicates that the consumer values an additional unit of good 1 the same, in terms of good 2, whether the consumer is only consuming a relatively small amount of good 1 (at point A) or a relatively large amount. The slope of the indifference curve gives the rate at which the consumer is willing to trade away good 2 for good 1 while staying at the same level of satisfaction. This rate does not change in this case, which indicates one extra unit of good 1 is a perfect substitute for a certain amount good 2.

Figure 3: Imperfect Substitute Preferences



When the indifference curve is bowed, as in Figure 3, the two goods are not perfect substitutes. At point A, the consumer has much good 2 compared to good 1, while at point C the consumer has much good 1 compared to good 2. Now, consider what happens when the consumer seeks one extra unit of good 1. Shifting from A to B, notice a large decrease in good 2 is necessary to put the consumer back to the same level of satisfaction after an additional unit of good 1 is received, while only a small decrease is needed with a shift from point C to point D. The changing rate of substitution indicates that the consumer values the extra unit of good 1 more when good one is scarce than when it is plentiful. In this case, goods 1 and 2 are not perfect substitutes. The rate at which the consumer is willing to trade good 2 for good 1 depends upon how much of each the consumer is already consuming. (This imperfect substitute case is probably more typical.)

A higher indifference curve indicates a higher level of satisfaction. This can be

understood by comparing points E and F in either Figure 2 or Figure 3. At point E, the consumer has more of both goods than at point F. Thus, the consumer should like point E better. Since all the points on the indifference curve containing E yield the same level of satisfaction, and since all the points on F yield the same, it follows that the consumer prefers all the points on the higher indifference curve to those on the lower indifference curve.

3. General Background

After discussing the basic consumer theory in terms of maximizing satisfaction, it is important to review research that has looked to either build upon or refute the consumer's ability to understand his or her own utility maximization. This section discusses a series of concepts that relate to the evolutionary models we build and is intended to provide the reader with some general background.

Economic Constraints That Consumers Actually Possess

“Deliberation cost” states that in the real world of consumer choice, a person's “cognitive resources” are scarce, meaning that it is extremely costly or time-consuming for someone to become aware of how the effects of a particular choice. Because there is a deliberation cost, the ability to make the most informed choice is affected.

The deliberation costs cause the consumer to examine other ways—social learning strategies—in which a consumer could determine an optimal, personally satisfying bundle. As explained by McElreath et al (2008), with information about the payoff of others, it is possible to have social learning. Similarly, as Conlisk (1980, 1995) notes, observed adaptive behavior can be explained as a response to the fact that people

cannot costlessly optimize in a one-shot fashion. Social learning can be very individually adaptive, providing cues that are reliable, leading to evolutionary dynamics similar to natural selection (McElreath et al, 2008, p. 8). Many authors, including Boyd and Richerson (2008), have argued that social learning—deemed cultural transmission—is an efficient shortcut to trial-and-error learning. Cultural transmission is to imagine a consumer without perfect information who tries to estimate what behaviors have been favored by selection in previous generation using observations of a finite sample of the population, its models.

Continuing with deliberation cost, Simon (1957) proposed alternative modeling where individuals are limited in the information that they possess, have cognitive constraints, and are limited in the time they have to make a decision. Simon's idea of modeling including deliberation cost is known as bounded rationality. With bounded rationality, because consumers lack the ability and resources to arrive at an optimal solution, consumers will apply their rationality, but only after their choices have been simplified (Simon 1972). Bounded rationality presents the consumer as a satisficer, meaning that the consumer seeks a satisfactory solution instead of the optimal one; hence, in the short-run, these decision-making techniques do not tend to promote optimality. Similar to the authors previously discussed, the research of Simon (1972) questions the feasibility of perfectly rational decisions. Due to limited decision-maker resources, bounded rationality revises the assumption of perfect rationality by accounting for the fact that perfectly rational decisions are often not feasible in practice due to the finite computational resources available for making them (Boyd and Richerson 1985).

Understanding and Describing Evolutionary Behavior in the Face of Deliberation Costs

In spite of deliberation costs affecting the ability to attain perfect information, decision-makers still manage to make decisions near optimal. The question many researchers ask, including Simon (1957) and Day (1984) is “how do they achieve the semblance of rationality?” In order to understand the process of decision-making, behavioral psychologists and decision theorists develop their models of learning. Although the models of different disciplines look to explain very different sorts of phenomena, these models, such as those of Simon (1957), Day (1984), and Houston and McNamara (1999) share four features. First, individuals have objectives or guiding criteria that allow them to rank possible outcomes of their behavior. Second, individuals make assumptions about the relationship between observed events in the environment and the outcome of future decisions. Third, because the observed events are imperfect indicators of the outcomes in the local environment, learning may lead to errors. Finally, individuals have an initial guess about what forms of behavior are best in the local environment (Boyd and Richerson 1985).

McElreath et al (2008) describes several kinds of social learning. Unbiased learning, wherein behavior is dictated strictly by copying others; positive frequency-dependence, which preferentially copies the most common behavior variants in the sample; and payoff-biased social learning, where a consumer adopts the behavior with highest average observed payoff. Positive frequency-dependence is expressed in one rule of cultural transmission. Cultural transmission is where the consumer, without perfect information, will try to estimate what behaviors have been favored by selection in previous generation using observations of a finite sample of the population. The cultural

transmission rule that utilizes positive-frequency dependence is for naïve individuals to adopt the average behavior of its models, leading to what has been called a “blending model” of inheritance, incorporated into mathematical modeling in this thesis (Fisher, 1958).

Game Theory and the Origins of Behavior Modeling

A way in which the social and individual learning strategies are modeled is through applying ideas drawn from evolutionary game theory, a logical extension of evolutionary theory (Gintis, 2005). It is the study of systems “in which individuals choose fitness-relevant responses,” and in which these responses evolve in a dynamic way (Gintis, 2005, p.8). Gintis, a major researcher in game theory, says modeling is beneficial in that it provides an approach to analyzing choice; although game theory modeling represents the irrelevant situation of choice in the presence of strategic interaction, many concepts can be extrapolated. For example, important to this study is Gintis’ rational actor model, which uses general evolutionary principles to suggest that decision-making can be “modeled as optimizing a preference function subject to informational and material constraints” (Gintis, 2005: 2). Generally, game theory has become the basic framework for modeling animal—including human—behavior (Alcock 1993; Krebs & Davies 1997; Maynard Smith 1976). In addition, it has helped shed the idea of a static and entirely self-interested character that we see when discussing basic economic theory (Gintis, 2000). The decision-makers in evolutionary game theory do not require formidable information processing capacities, so the recognition that there is a deliberation cost allows the use of evolutionary game theoretic models (Gigerenzer &

Selten 2001; Gintis, 2000). Therefore, it is useful to model individuals as considering only a restricted subset of strategy, the kinds of “rules of thumb” used in this research (Simon, 1972; Winter, 1971; McElreath et al, 2008).

Mating Model of Consumption: Bayesian Theory of Rational Choice

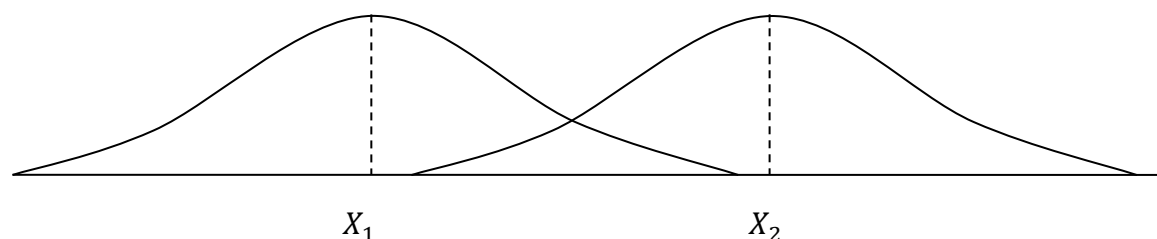
A detailed description of Bayesian theory and its applicability to behavior modeling is necessitated by the fact that it is the theory utilized in this thesis’ mating model of consumption, discussed later. The Bayesian theory of rational choice was developed as a normative theory of human decision-making in the presence of uncertainty as explained by Savage (1954). In the context of Bayesian decision theory, learning is thought of as using observations to modify one’s prior probability distribution of the outcomes that result from different decisions (Richerson 1985). The behavior governed by rational choice has the same three essential features as the much simpler models of learning used by behavioral psychologists. First, the Bayesian model of rational choice requires that the decision-maker be able to assign utility to outcomes. Second, it requires the decision-maker to make decisions about the nature of the environment (like knowing the likelihood function). Finally, this model of rational choice requires that the decision-maker make an assumption about the initial state of the environment in the form of a prior probability distribution.

An Advanced Model: Cultural Variance and the Forces of Guided Variation

The advanced evolutionary model in this research applies to the case of imperfect substitutes. In this case, we do not choose all of one good or the other for optimality; rather, we choose a mix of the two goods. Because of its modeling of a continuum of

choices, cultural variance is integral for the modeling of imperfect substitutes. Through social learning, we consider X , the cultural variant individuals acquire. To give an example of an application of this concept, consider X to denote the position of someone on the left to right of the political spectrum (Boyd and Richerson, 1985: 70). Further, suppose that an individual's behavior at any particular time can also be specified by a single number, Y , which might represent the individual's public statements on a particular political issue. We assume that, in general, people with the same X 's will have different Y 's. These differences can arise from several different factors, including a simple error like misunderstanding the issue. Additionally, the same cultural variant may result in different behaviors depending on the environment; for example, two equally radical politicians could express different opinions on a policy if they have different constituent interests. The opinions of the diametric opposite radical politicians, though, will be on average much different from each other. Cultural variance is shown graphically below.

Figure 4: Cultural Variance



With guided variation, decision-makers learn by experiencing their local environment and then modifying behaviors according to some “rule of thumb” criteria. The knowledge of a particular individual's determinants of learning should allow us to predict the behavior which will develop in a given environment. Some forces of guided variation can increase the frequency of behaviors that are genetically maladaptive;

however, adaptive advantages also can result from the fact that culture is an inheritance system, which will be discussed in the second model.

4. Standard Economic Model of Perfect Substitutes

A relatively simple evolutionary model can be constructed to explain consumption behavior when two goods are perfect substitutes. In this case, the consumer's optimal choice involves the consumption of only one of the two goods. To provide context for the evolutionary model constructed below, the standard economic model of how a consumer makes a decision when two goods are perfect substitutes is now presented, showing the best choice for the consumer involves the consumption of only one of the two goods.

Suppose the consumer receives the utility level $U = \alpha x_1 + (1 - \alpha)x_2$ from consuming x_1 units of good 1 and x_2 units of good 2, where α is the preference weight the consumer has for good 1 and $1 - \alpha$ is the weight for good 2. (If $\alpha = 1/2$, then the consumer likes the two goods the same, in a certain sense).

This consumer faces the budget constraint discussed previously, $p_1x_1 + p_2x_2 = I$. The price ratio, p_1/p_2 , is that amount of good 2 the consumer must give up in order to purchase one additional unit of good 1. The marginal rate of substitution is $\alpha/[1 - \alpha]$, which represents the amount of good 2 that the consumer is willing to give up to receive an additional unit of good 1 while remaining at the same level of satisfaction (Ahlersten 2008: 38).

If the marginal rate of substitution is greater than the price ratio, so $\frac{\alpha}{[1-\alpha]} > \frac{p_1}{p_2}$, then trading away good 1 for good 2 increases the utility of the consumer. Since the

marginal rate of substitution remains constant as this trade is made, the consumer will keep trading away good 2 until all income is spent on good 1. In this case, the utility of the consumer will have the consumer buying as much of good 1 as the income constraint will allow, consuming $x_1 = I/p_1$ and experiencing utility $U_1 = \alpha I/p_1$.

Alternatively, if $\frac{\alpha}{[1-\alpha]} < \frac{p_1}{p_2}$, then trading away good 1 for good 2 increases the utility of the consumer. The consumer will maximize utility by spending all income on good 2, so $x_2 = I/p_2$, and the consumer will experience utility $U_2 = [1 - \alpha]I/p_2$.

A special case occurs when $\frac{\alpha}{[1-\alpha]} = \frac{p_1}{p_2}$. In this case, the marginal rate of substitution equals the price ratio no matter what combination of the two goods is purchased. In this special case, the consumer rationally could consume a combination of both goods. This case would occur only by chance, and it is assumed it will not occur in what follows.

5. A Mating Model of Consumption

There is a population of identical consumers which recognizes goods A and B are perfect substitutes, so each consumer chooses either behavior A or behavior B. Suppose further that it is more costly for a consumer to change behavior and observe the result than to observe the behavior of another. That is, individual learning is more costly than social learning. By copying the behavior of others, imitators avoid costly learning trials, which are analogous to deliberation costs. Because of its cost advantage, it is assumed here that consumers use social learning rather than individual learning to increase well-being.

To make the model evolutionary, suppose all individuals choose their behavior, receive their payoffs, compare their behavior after a randomly being matched with another, and then update their chosen behavior accordingly. Let p denote the proportion of the population exhibiting behavior A before the random matching, so $1 - p$ is the proportion exhibiting behavior B. Let $P(i, j)$ denote the probability a consumer exhibiting behavior i is matched with consumer j . The i type consumer observes the behavior and outcome of the j type. Because the consumers are independently and randomly matched, we know

$$P(A, A) = p^2, P(B, B) = [1 - p]^2, P(A, B) = p[1 - p], \text{ and } P(B, A) = [1 - p]p.$$

If observing a higher payoff results in a change of behavior with probability 1, then there would be no evolution. All would change their behavior to the optimal choice after one interaction. One way to introduce evolution is to assume there is some uncertainty an individual will change behavior after observing the outcome of the other who behaves differently.

To introduce uncertainty, assume $P(i/k, j)$ is the probability a consumer will exit an interaction with behavior i when the consumer enters the interaction with behavior k and meets another with behavior j . It is logical that if two with the same behavior meet, there will be no change in behavior, so $P(A/A, A) = 1, P(B/A, A) = 0, P(B/B, B) = 1, P(A/B, B) = 0$.

Interacting with someone different will tend to change behavior, but not guarantee it.

Using a standard evolutionary transition rule (see Boyd and Richerson, 1985: 66), it is assumed

$P(A/A, B) = \frac{1}{2} + \beta[U(A) - U(B)]$ and, symmetrically, $P(B/A, B) = \frac{1}{2} + \beta[U(B) - U(A)]$.

Let p' denote the proportion of consumers exhibiting behavior A after the random matching process. The rules of conditional probability imply

$$p' = P(A/A, A)P(A, A) + P(A/A, B)P(A, B) + P(A/B, A)P(B, A) + P(A/B, B)P(B, B)$$

Substituting, we find:

$$(1) \quad p' = p^2 + 2p[1 - p] \left[\frac{1}{2} + \beta[U(A) - U(B)] \right],$$

or

$$(2) \quad p' = p[1 + 2[1 - p]\beta[U(A) - U(B)]]$$

The *replicator dynamic* for this model, $\Delta p = p' - p$, is

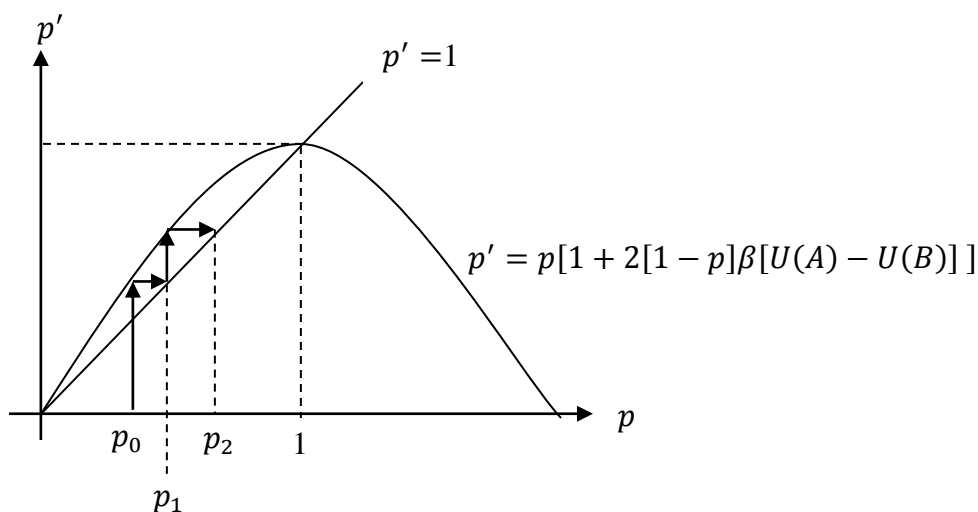
$$(3) \quad \Delta p = 2p[1 - p]\beta[U(A) - U(B)].$$

As discussed by Bomze (1995), the replicator dynamic is used to model many biological processes, not only in sociobiology, but also in population genetics. It usefully shows how the proportion of the population exhibiting a certain trait, here consuming all good 1, changes as a function of its current level. An equilibrium, where there is no change, when the population proportion p that solves $\Delta p = 0$. There are two equilibria for this model as long as $A \neq B$ initially: $p = 0$ and $p = 1$. (When $A = B$, the two characteristics are equivalent, and any value p is an equilibrium point.)

Figures 5 and 6 present the dynamics of the evolutionary model. Figure 5 plots Equation 2, and Figure 6 plots the replicator dynamic (Equation 3). Each model is

drawn under the assumption $U(A) > U(B)$, meaning consuming all good 1 is the optimal choice in the standard theory.

Figure 5: The Transition Equation for the Evolutionary Model



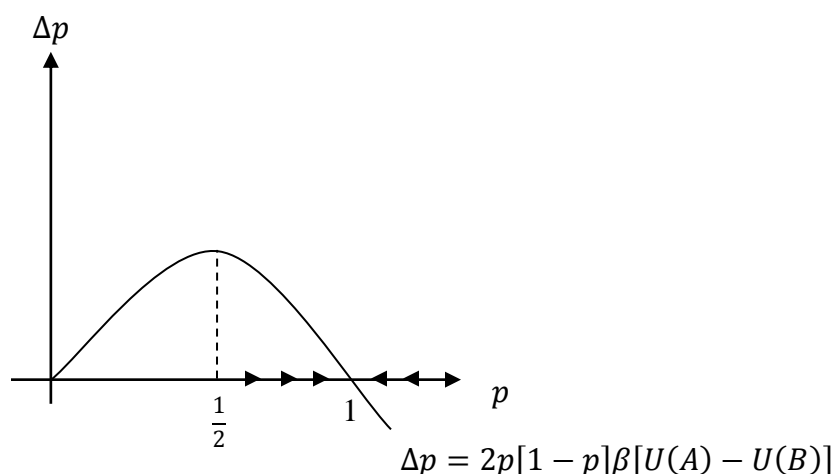
Phase diagram Figure 5 shows how the transition difference Equation 2 traces out the path of the proportion of the population exhibiting characteristic A (consuming all good 1). In Figure 5, the proportion p_0 is the initial portion of the population exhibiting characteristic A. After one application of the transition equation, the proportion is p_1 , and after two applications it is p_2 . The phase diagram indicates the proportion will converge over time to one, meaning eventually all in the population will exhibit characteristic A.

Formally, it can be proved whether or not a steady state is stable by evaluating the derivative of the transition equation at the steady state. From difference equation theory, the steady state is stable if this derivative is less than 1 but greater than -1. The derivative of the transition equation with respect to the proportion p is $1 + 2\beta[U(A) -$

$U(B)] - 4p\beta[U(A) - U(B)]$. Evaluating this condition at the steady state $p = 1$, we find that the derivative is equal to $1 - 2\beta[U(A) - U(B)]$. Because $U(A) > U(B)$, this derivative is less than 1. Figure 5 is drawn under the assumption that slope of the transition equation is zero at the steady state $p = 1$, so the equilibrium is stable, and the proportion p only increases over time.

However, the derivative at the steady state could conceivably be less than zero, and would be if $\beta[U(A) - U(B)] > 1/2$. In this case, the curve in Figure 5 would be shifted left, so the curve at the intersection point $p = 1$ would have a negative slope. In cases such as this, the path will cycle around the steady state, converging to it if the derivative is greater than -1 and diverging if the derivative is less than -1. In this particular model, it does not make sense that a proportion can cycle greater than 1, since it is not possible for more than 100 percent of the population to exhibit a characteristic. Thus, for this model to make sense, we must impose the restriction $\beta[U(A) - U(B)] \leq 1/2$. This implies the rate of adjustment β cannot be too large.

Figure 6: The Replicator Dynamic for the Evolutionary Model



The plot of the replicator dynamic in Figure 6 is also a phase diagram, but it shows how the change in the proportion with characteristic A evolves over time. Because the function is greater than zero for $0 < p < 1$, we know the change in the proportion is positive. The arrows shown along the horizontal axis provide an indication of how the proportion changes. In particular, the indication is that the proportion evolves toward one. That is, as with the transition equation, the replicator dynamic indicates the population learns to make the optimal choice.

Formally, for this type of phase diagram, a steady state is proven stable by evaluating the derivative of the function at the steady state. In this case, differential equation theory indicates that the steady state is stable if the derivative evaluated at the steady state is negative. The derivative of the replicator dynamic with respect to the proportion p is $-2\beta[U(A) - U(B)]p$. This is negative when evaluated at the steady state $p = 1$, so the steady state is stable.

Summarizing, this social learning model indicates in a stable environment a population of consumers with the same preferences can evolve toward an optimal choice. The primary assumption driving this result is the assumption that one person is more likely to imitate another when the other is experiencing a better outcome. As this greater likelihood has impact, the proportion adopting the better consumption choice increases, making it less likely that any individual meets someone choosing the inferior choice. The imitation allows the costs of deliberation to be avoided and the optimal choice eventually achieved by all.

6. Standard Economic Model of Imperfect Substitutes

Consider a consumer who faces the budget constraint $p_1x_1 + p_2x_2 = I$, but considers the two goods to be imperfect substitutes. In the case of imperfect substitutes, the decision-maker's optimal choice involves the consumption of both goods. The utility function implies goods 1 and 2 are imperfect substitutes is the log linear utility function $U = a \ln x_1 + (1 - a) \ln x_2$.

The marginal rate of substitution for this consumer is $ax_2/[1 - a]x_1$, which is not constant as consumption levels change. The choice for the consumer cannot be optimal unless this rate equals the price ratio p_1/p_2 , meaning $ax_2/[1 - a]x_1 = p_1/p_2$. The budget constraint $p_1x_1 + p_2x_2 = I$ must also be satisfied. These last two equations, imply the optimal choices for the consumer are $x_1 = aI/p_1$ and $x_2 = [1 - a]I/p_2$. We see the optimal choices depend upon three variables: (1) the consumer's income, the price of good 1, and the price of good 2.

For the purpose of building an evolutionary model, it is useful to note that the consumer's choice in this case amounts to choosing the fraction of income to devote to the purchase of good 1. Taking the optimal choice $x_1 = aI/p_1$ and solving for the parameter a , we obtain

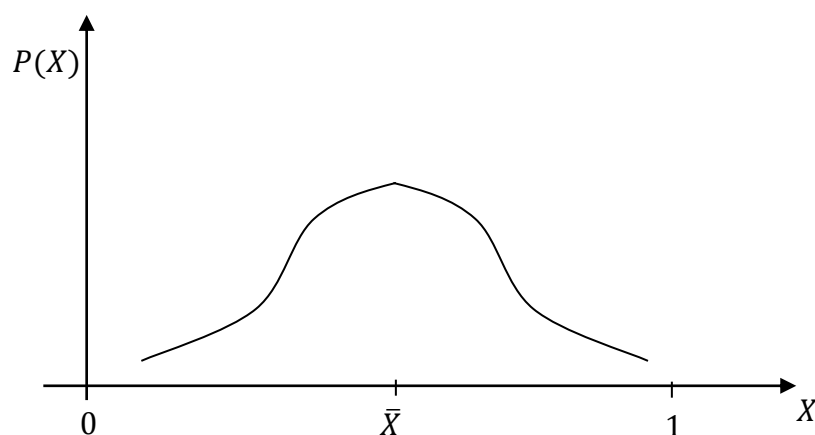
$a = p_1x_1/I$. Since p_1x_1 is the expenditure on good 1, p_1x_1/I is the fraction of income spent on good 1. This last equation indicates the optimal fraction of income to spend on good 1 is equal and amount equal to the parameter a . An effective evolutionary model will be one that can lead consumers to adapt over time so that in the long run in a stable environment this optimal fraction of income will be allocated to good 1.

7. An Advanced Evolutionary Model: Consumer Choice involving Imperfect Substitutes

As reviewed in earlier discussion, when goods x_1 and x_2 are imperfect substitutes, the optimal choice for the consumer will generally involve consuming some of each good. Thus, to construct an evolutionary model, we cannot posit just two cultural variants, as in the previous model. Rather than moving to three or any discrete number of possibilities, “It is more natural to model many culturally transmitted characteristics as having a continuous range of values” (Boyd and Richardson 1985:70). In our consumption context, this is equivalent to the consumer having the opportunity to choose any point along the budget constraint. To be specific, let X be the proportion of income the consumer spends on good 1. In our evolutionary model, this proportion distinguishes the cultural variant of the consumer, ranging between 0 and 1.

It is assumed that the population of consumers is large, and the proportion X of income allocated to good 1 varies. Let $P(X)$ denote the probability that a given consumer spends the proportion X . It is assumed $P(X)$ is a normal distribution with mean, \bar{X} and variance, V .

Figure 7: Distribution of Consumer Types



Each individual seeks the best choice by observing others. In particular, assume each individual observes the choice X_i of consumer i for n other consumers. However, assume there is some random observation error so the observed behavior of consumer i is

$$(4) \quad Z_i = X_i + e_i.$$

To keep the model simple, assume the observation errors $e_i, i = 1, 2, \dots, n$, are independent, have a zero mean, and have the same variance E .

Social learning is the basis of culture, and a culture is formed as each individual's cultural trait is biased by the behavior of the others according the "blending" rule

$$(5) \quad X' = \sum_{i=1}^{i=n} A_i Z_i,$$

where X' is the cultural trait of the consumer after the cultural transmission and A_i is the weight given to observed behavior Z_i . It is assumed the consumer being enculturated has an ability to measure the attractiveness of a given observation. Let $\beta(\cdot)$ be the rule used to measure the attractiveness, so $\beta(Z_i)$ is the perceived attractiveness of observation Z_i . This rule can then be used to construct the weight given to observed behavior Z_i using can then be specified as

$$(6) \quad A_i = \frac{\alpha_i(1+\beta(Z_i))}{\sum_{j=1}^{j=n} \alpha_j(1+\beta(Z_j))},$$

where α_i is a weight given to distinguish consumer i in some way other than the attractiveness of the observed decision. If $\alpha_i = \alpha$ for all i , then others are not distinguished in any way other than the attractiveness of the observed decision.

How might a consumer evaluate the attractiveness of an observed outcome Z_i ? A reasonable possibility is that there is some choice Z^* inherited as a cultural standard, and deviations from the standard are discounted. This behavior can be modeled by the Gaussian (Cordeiro 1991) bias function.

$$(7) \quad \beta(Z_i) = \frac{b}{e^{\frac{(Z_i - Z^*)^2}{2J}}} .$$

The highest attractiveness accorded to an observation is b , occurring when the observed behavior Z_i is the traditional behavior Z^* . The parameter J measures how much a deviation from the norm is penalized. When J is very small, even a small deviation from the norm is discounted almost completely, and not imitated. As J becomes very large, we move closer to the case where all observations are given the same weight, regardless of their distance from the norm.

Boyd and Richerson (1985: 141-144) show that a culture transmission model of this form yields the following cultural transmission from the social learning:

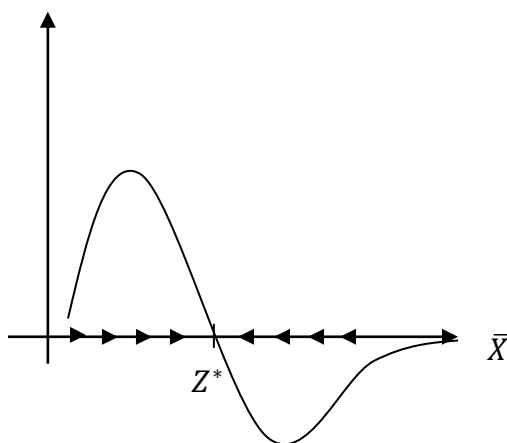
$$(8) \quad \bar{X}' = \bar{X} + B(\bar{X}).$$

Rearranging the above function, $B(\bar{X}) = \bar{X}' - \bar{X}$ gives the extent to which the mean choice of the population changes as a function of the location of the mean \bar{X} . Boyd and Richerson show the relationship between $B(\bar{X})$ and \bar{X} has the form shown in Figure 3.

The dynamics indicate that the mean choice in the economy will over time move to the traditional choice.

Figure 8: The Dynamics of the Average Consumer Type

$$B(\bar{X}) = \bar{X}' - \bar{X}$$



There is an interesting dynamic in Figure 8. If the initial mean is far from tradition, the mean will not move quickly at first. Rather, it will start slowly toward the tradition, but accelerate. Then, change will again slow as the tradition is approached.

Because the average consumer is led to the traditional choice in this social learning model, the ultimate nearness of the average consumer to an optimal choice depends upon how close the traditional choice Z^* is to the optimal choice. It was shown that standard theory indicates the optimal proportion of income to allocate to the consumption of good 1 is the parameter a . So, if there is some mechanism by which the traditional choice Z^* can evolve to the optimal proportion a , then the tradition will lead consumers to the optimal choice. Otherwise, the tradition, combined with the social learning, can lead the average consumer away from the optimum.

While it is not pursued here, evolutionary theory allows for a fitness function to be applied to a tradition. In particular, suppose $w(Z^*, a) = e^{-\frac{(Z^*-a)^2}{2s}}$ denotes the fitness of the tradition Z^* . The fitness function reaches a maximum when the tradition is optimal. Adding this fitness function to the model would allow more fit functions to be imitated with higher probability, which can lead the tradition to evolve, along with the mean behavior of consumers. In this way, the economy could evolve to the optimum.

8. Conclusion

This research demonstrates that a decision maker facing deliberation costs can cope with those costs by adopting an evolutionary or adaptive decision making approach. By imitating the behaviors of others and adapting in the direction of more fit behavior, the decision-maker can avoid deliberation costs and move, in a stable decision environment, toward the optimal choice over time. The two evolutionary models of consumer behavior presented in this thesis thus represent an extension of standard economic consumer theory, which assumes the consumer can costlessly optimize.

Two models have been presented, covering the case when goods are perfect substitutes and the case when the goods are imperfect substitutes. For the case of perfect substitutes, we assume a population of identical consumers learn socially what whether to spend all income on good 1 or all on good 2. Our mating model of consumption models demonstrated, the proportion of the population making the optimal choice will increase over time, converging ultimately to 100 percent.

For the case of imperfect substitutes, a more advanced evolutionary model was presented, but it also was based upon the cultural transmission of a choice characteristic

through social learning. In particular, social interaction influenced the proportion of income allocated to the consumption of a particular good, with a continuum of infinite possibilities between zero and one. This model also demonstrated that, with reasonable assumptions on social learning in a stable environment, a population can adapt over time and approach an optimal choice.

Because there are significant deliberation costs in the real world, this research may capture in a sense how consumers actually “choose” the goods they purchase. In the evolutionary world considered here, choice is much less conscience and proceeds with little reasoning. Yet, people nonetheless can live quite well. Further work must occur to further extend economic consumer theory in the evolutionary direction. Ultimately this clearly will required efforts from researchers in the different disciplines. From such research, we will have a better understanding of how consumer behavior is not only impacted by incentives, (which is the driving force in standard economic theory), but also by deliberation costs and other factors that will impact evolutionary adaptation.

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