

# The Evolution of Time Preferences: An Application of Contest Theory

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ABSTRACT: In this essay I develop a two period model in which consumption of the parents determines evolutionary success of the descendants via a contest. In order to derive a population genetic equilibrium, I make use of results derived in evolutionary biology and population genetics. The evolutionary processes as modelled in biology are very close to contest success functions as known in economics. The so-called Mean Fitness Increase Theorem, originally derived in genetics, is corroborated by my general results. Moving from a static to a dynamic environment has the potential to change the evolutionary processes dramatically.

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# 1. Introduction

In general, economists regard preferences and utility functions that are derived from preferences as something given, which they cannot explain. Preferences even seem to be somehow archaic, especially, as for example Robson (2001) points at, behaving as following a preference structure is not confined to human beings or to rationally acting individuals. Even valuation of the future is not confined to humans - Rogers (1994) argues that nest building and the like can be regarded as forgone consumption with a return in the future.

Still, some economists already dealt with the evolution of preferences, among the latest Konrad (2004). Most of them tried to explain the existence of envy or altruism in individual utility functions, which are deviations from the purely egoistic setting in standard household theory. Here, I want to consider something else, namely the exploration of the utility discount factor or of time preferences: Why are there differences in the valuation of the future, if a considerable degree of patience has such positive effects on wealth, and on all other types of capital, including health and human capital?

Beside individual effects, a decent preference for the future seems to be a factor for prosperity of a society as a whole: While dealing with a fragile environment with exhaustable resources, benefits from an investment made today which helps the society to prevail in the long run may not offer direct benefits to the individual who made that investment, or it may yield benefits that accrue very far in the future. Diamond (2005), pp. 294, exemplarily shows for Germany and Japan around the 17th century, how forest management was to the long run advantage of those societies; however, the benefit of planting a tree accrues (at least) after a couple of decades, which might be beyond the individual horizon.<sup>2</sup>

However, causality between prosperity and time preferences might just be the other way around, as Becker and Mulligan (1997) argue, namely that an individual with higher initial endowments can afford patience, while a poorer one is bound to "*live in the present*". So time preferences might rather be part of the outcome of an economic process than input for economic behavior.

Now, one has to decide how the evolution (and therefore the *change*) of preferences should be treated. Two potential ways can be identified:

1. *Individual* preferences could change, meaning that time preference changes during the lifetime of the individual under observation. There are two subcases to consider, namely whether the economic agent has the power to influence his preferences on his own (which would require something as *meta*-preferences), or his environment has an impact on his preferences beyond his own control. The first is proposed by Becker and Mulligan (1997), who introduce the possibility to invest

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<sup>2</sup>One may argue that this would not occur under perfect markets; however, for a market economy to be efficient, a market for every good has to exist, especially a market for *future* goods. But to establish a future market, at least some concern about the future has to be met.

in in the change of one's own discount factor. They argue that a higher valuation of the future might be achieved by gathering information about it, which again is costly.

2. If the assumption of invariant preferences is not abandoned, at least not on the individual level, the respective fractions of certain preferences within a population might still evolve over time. The mechanism behind is inheritance, such that the offspring behaves under the same (or correlated) preference structure as its parents.

The next step might include the question whether this only allows for a positive analysis, or if there are normative statements to derive as well. Usually, the analysis of evolutionary processes in economics is of a purely positive nature. But since time preferences may determine the economic outcome, a social planner might want to influence them. Think, for example, of cooperation among economic agents as of something the social planner would like to implement; if the possible interactions are such that they can be described by a repeated prisoner's dilemma, then the "shadow of the future" as referred to by Axelrod (1997) plays a key role in the individual decision on cooperation and defection. Now, the future can be rendered more important by decreasing the discounting of future payoffs.

How can an evolutionary process be modelled in detail? In genetics, there are the following major transmission mechanisms<sup>3</sup> by which genes are spread. First there is *mutation*. This is covered in a specific branch of economic models, e.g. one can speak of a *mutant* invading a population and ask whether the population is vulnerable to such an invasion (compare evolutionary game theory). Depending on which parameter is subject to evolution, mutation is by definition not restricted to existing types; so resistance to invasion has to be checked against all *possible* types. However, in the evolutionary process described in the following, mutation will be ruled out.

Second, there is *natural selection*. Here, types that already exist in the population have an increased or decreased probability of survival, depending on their adaption to environment. Contest theory seems to be especially qualified to model this feature of evolution, and selection will be the driving force in this essay.

Next, *non-random mating* (meaning that some types are more attractive either for all others or for a specific type) might influence the equilibrium as well as the path towards equilibrium. In the proposed model however, mating behavior has no influence. Of course, in the most general framework one would have to consider *gene flow*, caused by migration into or out of the population. All mechanisms together will tend to change the relative frequencies of types within a population, which the biologist calls the genetic drift. The mechanisms do not have to be applied deterministically, for example mutation is almost by definition a stochastic process, but also mating behavior or selection might be subject to random impacts.

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<sup>3</sup>Compare Cavalli-Sforza (2000), p. 42.

In this essay, I introduce economic behavior into some parts of the above mentioned mechanisms. The application of contest theory or evolutionary game theory might be particularly interesting, as both have their origins in biology or bio-economics, see e.g. Leininger (2003).

In section 2, I present the basic models of population genetics in a population of two types, possibly differing in their fitness. It is a specific form of the models known from population genetics. Without any economic decision making, the population equilibrium only supports total domination of one type, or no evolution at all (in the rare case in which both types are equal in fitness). In section 3, I introduce economic behavior of individuals, which leads to the general proposition that the type with the higher fitness will prevail, and finally dominate the population. Section 4 provides an example, while some proposals for the inclusion of a dynamic environment are made in section 5. I conclude in section 6.

## 2. The Biologist's View on Evolution

### 2.1. Random Mating, No Selection

In order to keep the evolutionary model as simple as possible, I restrict the analysis to one characteristic only. In terms of population genetics, the correct notions would be the following: The characteristic of interest (namely, the time preference) is determined by the occurrence of a specific *allele* on the "time preference" *locus* on the chromosome. Somehow, this occurrence determines the fitness either directly (which would be the biologist's view that is dealt with in this section) or indirectly via economic behavior. Obviously, behavior and/or fitness is not determined by one characteristic or locus alone, but by the interaction of many loci, which would, however, render the analysis much more complicated.

Suppose the two possible alleles (types) are  $\delta_h$  and  $\delta_l$ . If one allows for random mating, it has to be dissolved what happens once a  $\delta_h$ -type reproduces with a  $\delta_l$ -type. Usually, this implies the occurrence of a  $\delta_{hl}$ -type, but I abstract from this. Denote the respective shares in a population by  $\alpha$  and  $1 - \alpha$ . If types are matched randomly, an  $\delta_h$  individual meets another  $\delta_h$  individual with probability  $\alpha^2$ , while the  $\delta_l$ -type meets one of his kind with the probability of  $(1 - \alpha)^2$ . All individuals that reproduce with an individual of the same type will have look-alike descendants. If a  $\delta_h$ -type meets a  $\delta_l$ -type, the outcome will be the  $\delta_l$ -type with a probability of one half, and with one half the  $\delta_h$ -type. Selection is neglected for the time being, so after one round of mating, the frequencies at  $t + 1$  can be denoted by

$$\alpha_{t+1} = \alpha_t^2 + \alpha_t(1 - \alpha_t) \quad (1)$$

$$= \alpha_t \quad (2)$$

$$1 - \alpha_{t+1} = (1 - \alpha_t)^2 + \alpha_t(1 - \alpha_t) \quad (3)$$

$$= 1 - \alpha_t. \quad (4)$$

This holds for every  $t$ , so the initial distribution of types will be the equilibrium distribution. Note that this is a simplified version of the Hardy-Weinberg law<sup>4</sup>, which states that under random mating without selection, the equilibrium distribution is in general reached after one round of mating (which would be exactly the result if the  $\delta_{hl}$ -type was introduced here).

## 2.2. Random Mating and Selection

Now suppose that we can assign a certain *fitness* to the types, depending on the environment  $R$ , and denote the fitness as  $\tilde{F}(\delta_h, R)$  and  $\tilde{F}(\delta_l, R)$ , respectively. These values shall be important only in a relative sense, such that one of them can be normalized to 1. The remaining fitness  $F(\delta_h, \delta_l, R) = \tilde{F}(\delta_h, R)/\tilde{F}(\delta_l, R)$  is now said to be superior if  $F(\delta_h, \delta_l, R) > 1$ , and inferior if  $F(\delta_h, \delta_l, R) < 1$ . Of which size ever,  $F(\cdot)$  augments the probabilities in the mating process. The interpretation is that the offspring *born* is still determined by the rules already mentioned above. However, some are relatively more successful in reaching the age in which they can reproduce themselves, and this *survival* is measured by  $F(\cdot)$ . In order to restrict the sum of the frequencies to one, the fitness-augmented process has to be normalized by a constant of proportionality, which is here

$$\hat{F} = F(\delta_h, \delta_l, R)\alpha + (1 - \alpha). \quad (5)$$

So the frequency of those reaching adult age is given by

$$a_{t+1} = \frac{F(\delta_h, \delta_l, R)(\alpha_t^2 + \alpha_t(1 - \alpha_t))}{\hat{F}}, \quad (6)$$

or in terms of the difference  $\Delta_t$ ,

$$\alpha_{t+1} - \alpha_t = \frac{\alpha_t(1 - \alpha_t)(F(\delta_h, \delta_l, R) - 1)}{F(\delta_h, \delta_l, R)\alpha + (1 - \alpha)}. \quad (7)$$

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<sup>4</sup>See Ewans (2004), pp. 3.

## 2. The Biologist's View on Evolution

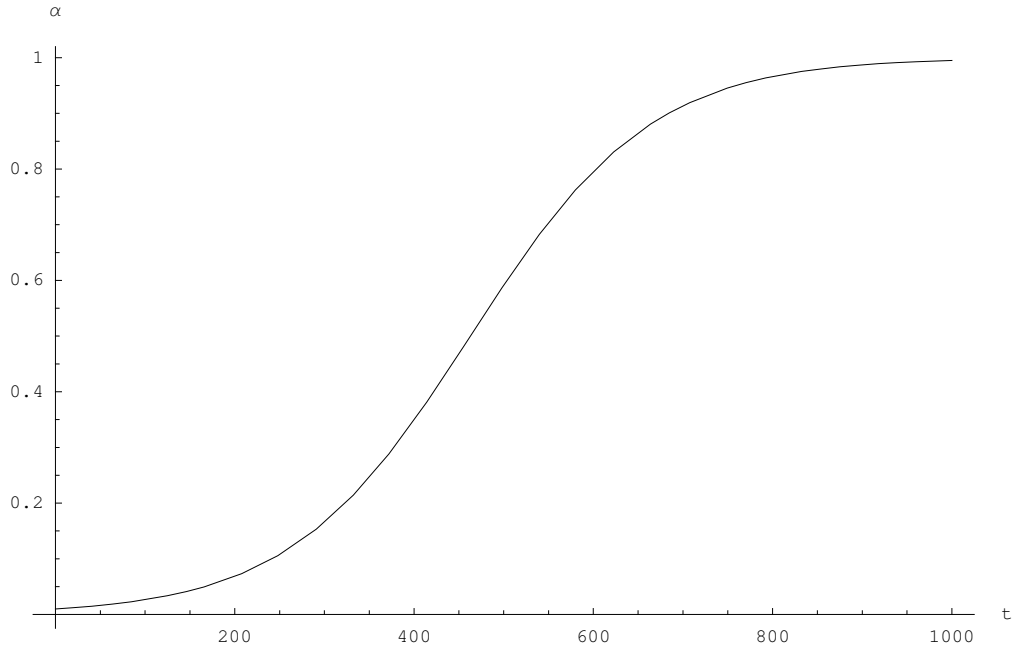


Figure 1: Evolution of  $\delta_h$ -Type with  $F(\cdot) = 1.01$  and  $\alpha_1 = 0.01$

Note that this concept resembles a contest success function of the Tullock type, see Nitzan (1994) for an overview. The difference equation for  $\alpha_t$  has a general solution for every  $t$ , depending on  $F(\cdot)$  and the starting value  $\alpha_1$ :

$$\alpha_t = \frac{\alpha_1(1/F(\delta_h, \delta_l, R))^{-t}}{(1 - \alpha_1)F(\delta_h, \delta_l, R) + \alpha_1F(\delta_h, \delta_l, R)^t} \quad (8)$$

Under the obvious assumptions of  $\alpha_1 \in [0, 1]$  and  $F > 0$ , the limit of this solution for  $t \rightarrow \infty$  is either 0 or 1, depending on whether  $F(\cdot)$  is smaller or larger than 1. But note that even in this pure biological setting, the limit of  $\Delta_t$  for  $t \rightarrow \infty$  goes to zero, so the "marginal productivity" of a better fitness decreases as its occurrence becomes overwhelming. Or in other words - see Gillespie (1998), p. 55 - the selection mechanism "*is most effective when genetic variation is near its maximum [...]*". So the relative success of a superior type depends on the frequency of its occurrence. If, for example, the type of interest is only marginally superior with  $F(\cdot) = 1.01$  and it is not wide spread with  $\alpha_1 = 0.01$ , the evolution of  $\alpha$  is such that the marginal productivity of fitness is even increasing within the first generations, and declining again, once this type dominates the population; see figure 1 for the evolution of the fraction of the  $\delta_h$ -type.

### 2.3. Non-Random Mating

First consider a generalization of the above stated Hardy-Weinberg law, which allows for a deviation from random mating.<sup>5</sup> Selection is neglected again for the time being. I introduce a probability  $\beta$  which denotes the chance that an individual of whatever type mates with an individual of his own kind. The counter probability denotes the chance for random mating. So the rudimentary difference equations are given by

$$\alpha_{t+1} = \alpha_t^2(1 - \beta) + \alpha_t(1 - \alpha_t)(1 - \beta) + \alpha_t\beta \quad (9)$$

$$= \alpha_t \quad (10)$$

$$1 - \alpha_{t+1} = (1 - \alpha_t)^2(1 - \beta) + \alpha_t(1 - \alpha_t)(1 - \beta) + (1 - \alpha_t)\beta \quad (11)$$

$$= 1 - \alpha_t. \quad (12)$$

Without differences in fitness, the relative frequencies remain the same ad infinitum. Including selection (and therefore relative fitness) yields

$$\alpha_{t+1} = \frac{F(\delta_h, \delta_l, R)\alpha_t}{\widehat{F}} \quad (13)$$

$$\text{with } \widehat{F} = F(\delta_h, \delta_l, R)\alpha_t + (1 - \alpha_t). \quad (14)$$

The solution of this difference equation is the same as the one of the random mating and selection case considered above, and it is especially independent of  $\beta$ , which is mainly due to the fact that the mixed genotype  $\delta_{hl}$  is omitted.

## 3. Introducing Economic Behavior

### 3.1. Individual Behavior

In the following,  $F(\delta_h, \delta_l, R)$  will not be given exogenously; it will be the outcome of economic behavior (which is admittedly ultimately determined by the type,  $\delta_h$  or  $\delta_l$ ).

Suppose that an individual lives for two periods and draws utility from consumption  $x_1$  and  $x_2$  in the respective period. The individual is endowed with one unit of a storable good, so the decision that has to be made in the first period is on the amount of consumption and savings. The individual will not be able to enjoy consumption in the second period to the same degree as in the first one: His preferences are such that consumption in the second period is discounted by an exogenous factor  $\delta$ . Secondly, the individual can invest in his ability to draw utility in the second period. For reasons of simplicity assume that the endogenous investment made in the first period is equal to consumption in the first period. Though merely a matter of interpretation, note that

<sup>5</sup>Compare Gillespie (1998), pp. 86 and Ewans (2004), pp. 18.

the investment of what ever kind does *not* influence the time preferences themselves, which remain exogenous from the individual point of view.

An alternative interpretation of this investment made in the first period is that  $x_1$  increases the probability to survive until period 2 rather than it increases the utility drawn from  $x_2$ . If the individuals cannot borrow from the future, both interpretations are equivalent. However, the latter becomes especially meaningful in the next section, where the example combines the exogenous discounting  $\delta$  with the endogenous survival probability  $x_1$  by simple multiplication, such that overall weighting of future consumption is  $\delta x_1$ .

The population can make use of a storage technology that transfers the good one period ahead. This is not necessarily the capital market; in a more archaic setting this might simply be a fraction of the this years's harvested crop which is not consumed, but kept for the next growing season. Let  $R$  denote this technology that transfers  $1 - x_1$  to the future. In general,  $R$  could be any function, but for the ease of exposition let  $R$  resemble an interest factor. Since stored crop can either be rotten until the next season or else allow for high yields,  $R$  is not restricted to be larger or smaller than 1. The individual maximization problem is then

$$\max_{x_1, x_2} u(x_1) + \delta u(x_1, x_2) \quad \text{s.t.} \quad x_2 = R(1 - x_1), \quad (15)$$

which yields  $x_1^*$  and  $x_2^*$ , ultimately depending on the time preferences.<sup>6</sup>

### 3.2. Population Dynamics by Natural Selection

Assume now that a population of a unit mass consists of two groups that only differ with respect to their discount factor. The two groups are indexed by  $i = h, l$ . Each individual gives birth to one child, which in turn inherits the time preference rate. Consider that mating is random, which comes at no loss of generality in this setting, as shown in section 2.

The survival probability of each child depends on the relative strength of his parents. The strength itself is determined by second period consumption  $x_2$  (augmented by the probability or the effectiveness of second period consumption, which is measured by  $x_1$ ). Note that there is neither altruism towards the own children, nor is there a decision to be taken whether an individual reproduces or not. In other words, every individual is not concerned about the future of his genotype. Using  $t$  as index for each generation and  $\alpha \leq 1$  as the fraction of individuals with the  $h$ -preference for future consumption,

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<sup>6</sup>See Gollier (2001), p. 219, for a justification of a utility function that is additively separable in time. He argues that exponential discounting in the case of multiple periods by  $u_t(x_t) = \rho^t u(x_t)$ ,  $\rho \in (0, 1)$  is justified once  $\rho$  is conceived as the probability of survival from period  $t$  to the subsequent period, with the property of  $\lim \rho^t u(x_t) \rightarrow 0$  as  $t \rightarrow \infty$ . However, in this setting this required  $\delta \in (0, 1)$ .

the mass of individuals of the same type in the next period is given by

$$\alpha_{t+1} = \frac{\alpha_t g(x_{1h}^*, x_{2h}^*)}{\alpha_t g(x_{1h}^*, x_{2h}^*) + (1 - \alpha_t) g(x_{1l}^*, x_{2l}^*)}, \quad (16)$$

which is the known difference equation for an evolutionary process with random mating and selection, once  $g(x_{1h}^*, x_{2h}^*)/g(x_{1l}^*, x_{2l}^*)$  is replaced by  $F(\delta_h, \delta_l, R)$ . Introducing a fitness function of the kind that depends on economic behavior is the main difference to the usual evolutionary theory, where fitness or the prior distribution of fitness is assumed to be exogenous - compare for example Ewans (2004), pp. 53.

Turning to the solution of this difference equation and hence to the population equilibrium, one finds that there are cases, in which the fitness function is monotonously increasing or decreasing in the genotype - in these cases, the highest (or lowest) occurrence of the allele will finally take over the population. In addition, no equilibrium of this kind is evolutionary stable, as every mutant with a higher (or lower) parameter value than observed in the equilibrium will take over the population.

In other (more interesting) cases,  $\alpha_{t+1}(\delta_h, \delta_l, R)$  and therefore the equilibrium  $\alpha$  has an interior extremum. Then it is not obvious, which subpopulation will prevail, or whether they might evolve a coexisting equilibrium in the long run. In general, this will depend on the degree of adaption to environment, hence on the respective fitness. As in the contest success function only relative levels determine the outcome, the equilibrium will depend on the relative fitness of  $\delta$  compared with the exogenous environment, which is represented by  $R$ . Such a measure for relative fitness has already been defined in section 2 by  $F(\delta_h, \delta_l, R)$ , and it will ultimately depend on the functional form used for utility.<sup>7</sup>

Despite the lack of explicit expressions until now, the following proposition 1 lies at hand:

**Proposition 1.** *The subpopulation  $h$  with  $F(\delta_h, \delta_l, R) > 1$  will prevail in the long run, and it will perish if  $F(\delta_h, \delta_l, R) < 1$ .*

From this directly follows

**Corrolary 1.** *A coexisting equilibrium can only be supported, if and only if*

$$F(\delta_h, \delta_l, R) = 1 \quad \text{and} \quad 0 < \alpha_1 < 1. \quad (17)$$

However, note that the latter does not necessarily imply  $\delta_h = \delta_l$ . Proposition 1 is consistent with the Mean Fitness Increase Theorem (MFIT)<sup>8</sup> as derived in biology,

<sup>7</sup>The functional form of  $g$  is not a decision to be taken in its own right, since it is already determined by the part of  $u$  that describes how  $u(x_2)$  depends on the prior consumption of  $x_1$ . In general, the contest success function (meaning the difference equation describing the evolutionary process) may be altered as well, which is subject to future considerations.

<sup>8</sup>Compare Ewans (2004), pp. 16.

#### 4. An Example

which states that without mutation, the average fitness increases over time; in the terminology used here, this means:

$$\widehat{F}_t \geq \widehat{F}_{t-1} \quad (\text{MFIT}) \quad (18)$$

$$\text{with } \widehat{F}_t = \alpha_t F(\delta_h, \delta_l, R) + (1 - \alpha_t) \quad (19)$$

Equality is left as a possibility, since equality in fitness should not be ruled out. A type with a strictly dominating fitness function in terms of the distance or appropriateness to the environmental restriction  $R$  will takeover the population in a stepwise manner, such that the mean of the time preferences in equilibrium (and on the path to equilibrium) is more successful than than the mean of any initial distribution of types from which the equilibrium was derived. Depending on functional forms, this might imply that this mean is *closer* to  $R$ . Note that the MFIS in this section is purely based on the frequency change alone, and not on the introduction of a new type of time preferences, as would be the case if the types themselves, or the number of possible types, developed over time.

## 4. An Example

### 4.1. Individual Behavior

In order to derive some explicit results, I assume specific functional forms. Let lifetime utility be formulated as

$$u(x_1, x_2) = x_1 + \delta x_1 x_2. \quad (20)$$

In this case, there is no need for consumption smoothing; the only reason to have positive savings is an  $R$  which is large enough such that the individual is willing to make use of the storage technology. The budget constraint is given by

$$x_2 = R(1 - x_1), \quad (21)$$

hence the storage technology is such that  $R$  can be interpreted as interest factor, which can in principle be larger or smaller than one.

Straight forward maximization of individual utility yields

#### 4. An Example

$$x_1^* = \frac{R\delta + 1}{2R\delta} \quad (22)$$

$$x_2^* = \frac{R\delta - 1}{2\delta}. \quad (23)$$

The solution is unique, and contemporary consumption is monotonously decreasing in  $\delta$ . Additionally, one might want to assume further that  $R\delta \geq 1$ , which guarantees that both  $x_1^*$  and  $x_2^*$  are non-negative. However, this restriction is not necessary.

### 4.2. Population Dynamics by Natural Selection

Now that  $x_1^*$  and  $x_2^*$  have been found, denote absolute fitness by  $g(x_{1i}^*, x_{2i}^*)$  for both types of individuals,  $i = h, l$ . With  $g(x_{1i}^*, x_{2i}^*) = x_{1i}^* x_{2i}^*$ , relative fitness of the  $h$ -type is then given by

$$F(\delta_h, \delta_l, R) = \frac{g(x_{1h}^*, x_{2h}^*)}{g(x_{1l}^*, x_{2l}^*)} \quad (24)$$

$$= \frac{\delta_l^2 (\delta_h^2 R^2 - 1)}{\delta_h^2 (\delta_l^2 R^2 - 1)} \quad (25)$$

Using this solution with equation 8, the general solution for the difference equation of the population dynamics, yields an explicit, but complicated term; see the appendix.

However, even in this relatively simple example, the dominating type is not determined by the highest preference for the future alone; there is an interior interval for  $\delta_h$ , in which the  $\delta_h$ -type will *not* prevail. For  $\alpha_1 = 0.5$ ,  $R = 1.5$ , and  $\delta_l = 1$ , compare figure 2. The explicit boundaries of this interval are given at  $F(\cdot) = 1$ . In this case, an equilibrium is reached instantaneously, as the initial population does not change anymore. If only positive values for  $\delta$  and  $R$  shall be allowed, an equilibrium with  $\delta_h$  as the dominant type can be described by the following proposition 2:

**Proposition 2.** *For  $\delta_h$ ,  $\delta_l$ , and  $R$  being positive,*

$$\begin{aligned} g(x_1, x_2) &= x_1 x_2 \\ u(x_1, x_2) &= x_1 + \delta x_1 x_2, \end{aligned}$$

*the  $\delta_h$ -type will prevail in the equilibrium population if*

1.  $\delta_h < \delta_l$  and  $\delta_h > 1/R$ , or
2.  $\delta_h > \delta_l$  and  $\delta_h < 1/R$ .

*Both cases describe the conditions for  $F(\delta_h, \delta_l, R) > 1$ .*

*Proof.* The result is obtained by using the inequalities  $F(\delta_h, \delta_l, R) > 1$ ,  $R > 0$ ,  $\delta_h > 0$ , and  $\delta_l > 0$ .  $\square$

In case (1), the subpopulation with the lowest preference for the future prevails, whereas in case (2), the subpopulation with the highest  $\delta$  dominates. In both cases, the dominating type has an advantage in exploiting the environmental restriction  $R$ , by consuming more in the period in which consumption is easier to obtain.

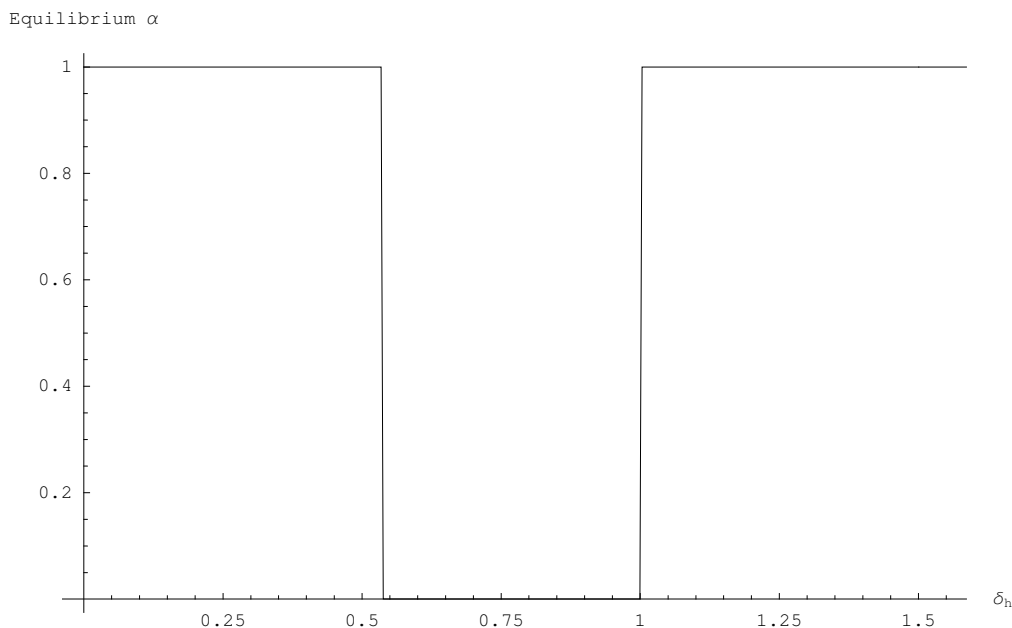


Figure 2: Equilibrium  $\alpha$  as Function of  $\delta_h$

Note that proposition 1 and its corollary still apply. Again, the attained equilibrium is still not evolutionary stable. Since I abstain from mutation, the so-called *Mean Fitness Increase Theorem*(MFIS) also applies.

## 5. Population Dynamics - Adaption to a Dynamic Environment

Imagine the environment is changing over time, which is represented by a fluctuating  $R$ . Since all individuals only live for two periods and are not altruistic towards their offspring, they are generically not interested in the exact pattern of the fluctuation, as their economic decisions do not depend on it. The process that governs  $R$  might be purely deterministic or of stochastic nature; both would be easy enough to implement, since individual expectations do not matter.

Suppose that five basic patterns of the dynamic environment can be identified:  $R$  is constant, cyclic, increasing, decreasing in  $t$ , and auto-regressive (see appendix for the

respective data generating processes). With a monotonously increasing or decreasing  $R$ , the adaption of the relative fractions in the population resemble the evolution in a static environment; however, depending on the absolute sizes of  $\delta_h$  and  $\delta_l$ , as well on the difference between both, the adaption may be faster or slower.

With a cycling behavior of  $R$  (following a sinus-wave), the adaption becomes anything else than trivial; e.g., take the case of  $\delta_h = 0.95$ ,  $\delta_l = 0.9$ , and a starting value of  $\alpha_1 = 0.5$ , the evolutionary process until  $t = 500$  can be seen in figure 3. An intuitive interpretation of such an evolutionary pattern is still pending. Much more reasonable seems to be the process as described in figure 4, where the fraction of the type with higher fitness increases cycling, but monotonously.

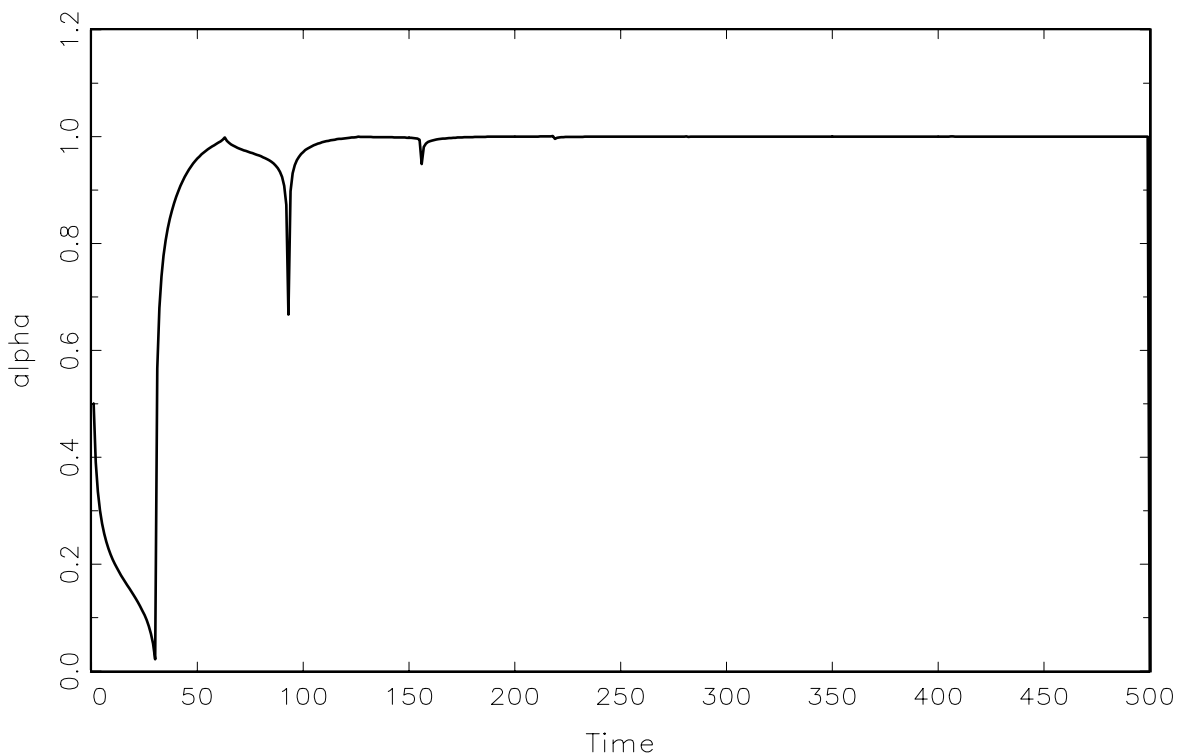


Figure 3: Evolution of Fraction  $\alpha$ ,  $R = \sin(0.1t) + 1.01$ ,  $\alpha_1 = 0.5$

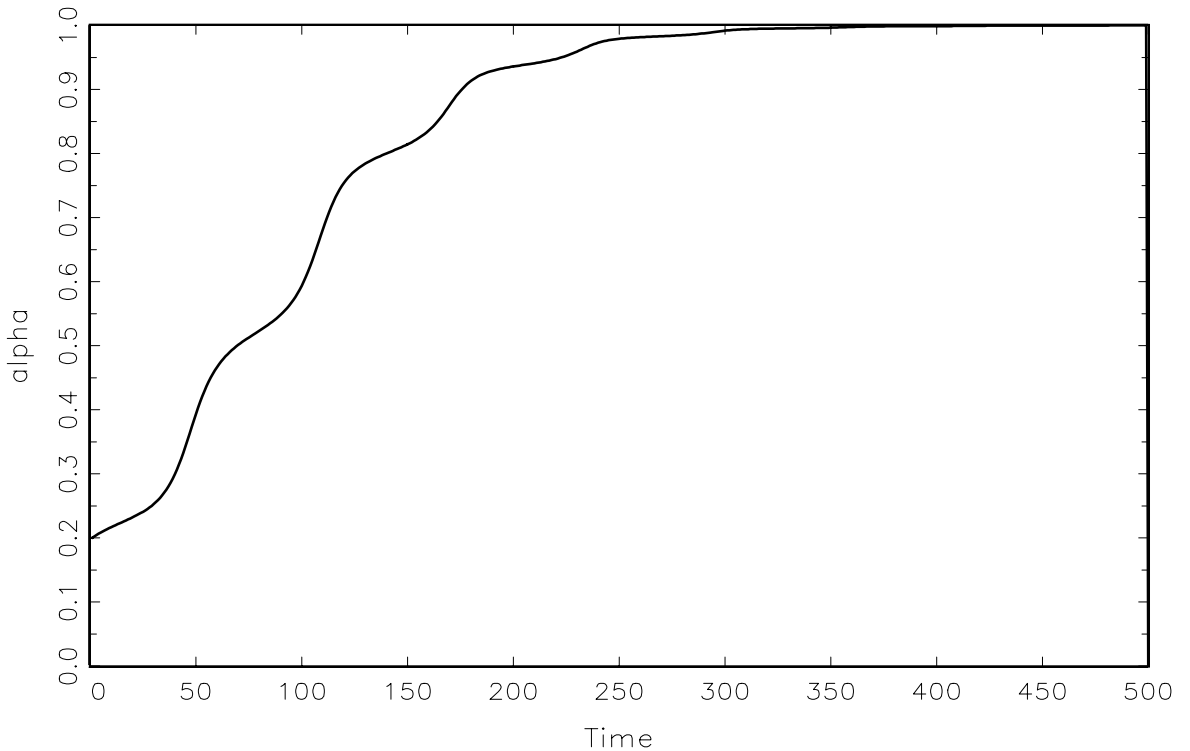


Figure 4: Evolution of Fraction  $\alpha$ ,  $R = \sin(0.1t) + 3$ ,  $\alpha_1 = 0.2$

## 6. Conclusion and Outlook

A patient behavior seems to have clear advantages, as only a patient individual will be able to accumulate capital of whatever kind. And it seems reasonable at the same time to model an evolutionary contest in which the number of descendants depends positively on consumption of their parents. Reinventing rather standard evolutionary processes as already known in biology yields the robust result that the time preference type, which is (conditioned on the environment) superior will take over the whole population. Further work should apply evolutionary processes that are closer to our biological reality; especially the introduction of mixed-type individuals as the offspring of different parents might change the path to equilibrium. However, as textbooks in population genetics indicate, the Mean Fitness Increase Theorem (which finally leads to the dominance of one type) will still prevail.

The coexistence of different types can in this model only be explained by a fitness function that is not monotonously increasing or decreasing in the individual valuation of the future. Such a fitness function would allow two different types to have the same fitness. Outside the presented model, however, one might think of additional economic mechanisms that allow for different evolutionary paths. The introduction of additional dynamics as thought of in section 5 only serves as a first step, and especially some resulting evolutionary patterns still wait for an explanation.

Mutual influence of economics and population genetics seems to be promising. Economists can rely on research on evolutionary processes already published decades ago (and find that contest theory has its justification right from there), while biologists might benefit from economics, which is potentially able to explain the fitness function as an outcome of economic behavior, rather than assuming it exogenously.

## A. Solution of the Difference Equation in Section 4.2

$$\alpha_t = \frac{\alpha_1 \delta_h^2 (\delta_l^2 R^2 - 1) \left( \frac{\delta_l^2 (\delta_h^2 R^2 - 1)}{\delta_h^2 (\delta_l^2 R^2 - 1)} \right)^{-t}}{\alpha_1 \delta_h^2 \left( \frac{\delta_l^2 (\delta_h^2 R^2 - 1)}{\delta_h^2 (\delta_l^2 R^2 - 1)} \right)^t (\delta_l^2 R^2 - 1) + (1 - \alpha_1) \delta_l^2 (\delta_h^2 R^2 - 1)} \quad (26)$$

## B. Possible Data Generating Processes for $R$

$$R_{\text{const}}(t) = 1 \quad (27)$$

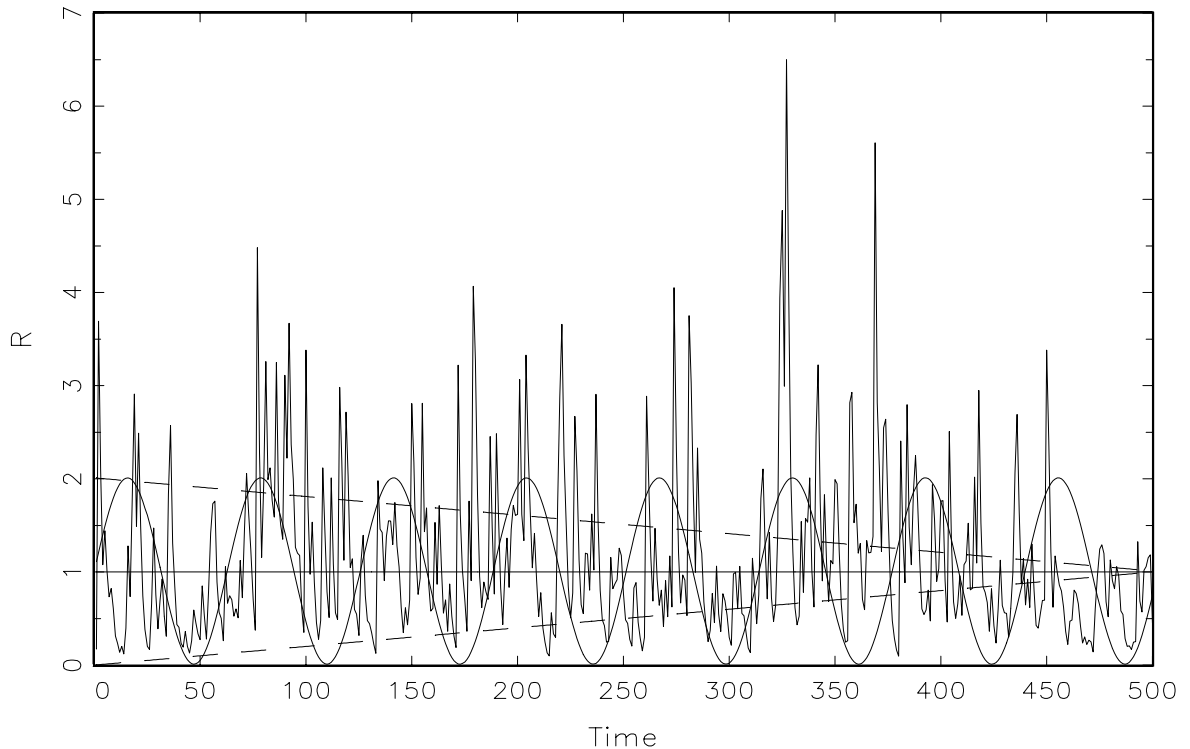
$$R_{\text{cycl}}(t) = \sin(0.1t) + 1.01 \quad (28)$$

$$R_{\text{incr}}(t) = \frac{t}{T} \quad (29)$$

$$R_{\text{decr}}(t) = 2.01 - \frac{t}{T} \quad (30)$$

$$R_{\text{AR}}(t) = 0.01 + 0.5R(t-1) + \epsilon(t)^2, \quad \epsilon(t) \sim N(0, 1) \quad (31)$$

The respective functional forms are chosen such that a strictly positive  $R$  is guaranteed. See figure 5 for an example with  $T = 500$ .

Figure 5: Evolution of Environment  $R$ 

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