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# Dynamic Optimization and Conformity in Health Behavior and Life Enjoyment over the Life Cycle

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## Comments

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## Abstract

*This article examines individual and social influences on investments in health and enjoyment from immediate consumption. We report the results of a lab experiment that mimics the problem of health investment over a lifetime, building on Grossman's (1972a, 1972b) theoretical framework. Subjects earn money through the experiment in proportion to the sum of the life enjoyment they have consumed. However, income in each period is a function of previous health investments, so there is a dynamic optimum for maximizing earnings through the appropriate expenditures on life enjoyment and health in each period. In order to model social effects in the experiment, we randomly assigned individuals to chat/observation groups, composed of four subjects each. Two treatments were employed: In the Independent treatment, an individual's rewards from investments in life enjoyment depend only on his choice and in the Interdependent treatment, rewards not only depend on an individual's choices but also on their similarity to the choices of the others in their group. Seven predictions were tested and each was supported by the data. We found: 1) Subjects engaged in helpful chat in both treatments; 2) there was significant heterogeneity among both subjects and groups in chat frequencies; and 3) chat was most common early in the experiment. The interdependent treatment 4) increased strategic chat frequency, 5) decreased within-group variance, 6) increased between-group variance, and 7) increased the likelihood of behavior far from the optimum with respect to the dynamic problem. Individual incentives explain a large part, but not all, of the variance in prosocial behavior in the form of strategic advice. Incentives for conformity appear to promote prosocial behavior, but also increase variance among groups in equilibrium outcomes, leading to convergence on suboptimal strategies for some groups.*

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## 1. Introduction

Inequalities in health, across and within populations, are a major public concern that demand attention (Murray et al. 1999). For example, the life expectancy of Native American males is 56 years in some counties, while that of Asian American women is 95 years in other counties (Murray et al. 1998). While several critical variables such as income and education help explain these differences, significant variance remains unexplained (Cutler and Lleras-Muney 2010). Other explanatory variables are related to health behavior, exercise, and dietary habits. In fact, health behavior explains about 40 percent of premature mortality, as well as substantial morbidity and disability, in the United States (McGinnis et al. 2002).

Empirical evidence shows that social groups influence health behavior in complex ways. Peer pressure can help individuals control health habits (Umberson et al. 2010). For example, spouses or religious communities may monitor, inhibit, regulate, or facilitate the health behavior of their partners or members of their community (Waite 1995, Ellison and Levin 1998). Group effects alternatively might lead individuals to engage in risk-taking and increased alcohol consumption. In addition, there seem to be matching effects; for example, having an obese spouse or friend can increase an individual's likelihood of being obese (Christakis and Fowler 2007; Crosnoe et al. 2004). Despite the extensive evidence of group influence in health behavior, little is known of the precise mechanisms by which groups influence individual choices. Identifying the social causes of behavioral change from naturally occurring data is difficult due to selection biases and unobserved heterogeneity associated with group formation (Fowler et al. 2011). In addition, interactions between individuals and groups that affect health behavior are usually unobserved.

This article examines individual and social influences on investments in health and enjoyment from immediate consumption. We do this in a specially framed lab experiment that mimics the problem of health investment over a lifetime, building on Grossman's (1972a, 1972b) theoretical framework to study health investment choices. Choosing optimal health investments over the life course is a complex task. Individuals might estimate well the current costs and benefits of their actions but be less certain of their long-run effects. In essence, to determine how much time, income and effort to invest in healthy behavior, individuals have to solve a dynamic programing problem addressing uncertainty concerning future income and progressive health degeneration.

In the lab, our subjects experienced an experimental environment that mimics the previously described health-investment problem. Each subject lives a nine-period life, during each period of which he earns income and then invests some proportion of that income in health and some in life enjoyment. Subjects earn money through the experiment in proportion to the sum of the life enjoyment they have consumed. However, income in each period is a function of previous health investments, so there is a dynamic optimum for maximizing earnings through the appropriate expenditures on life enjoyment and health in each period. Subjects live eight lives during the experiment with identical parameter values, so they can learn from experience.

In order to model social effects in the experiment, we randomly assigned individuals to chat/observation groups, composed of four subjects each. Between lives, subjects were allowed to chat with and observe the choices of others in their chat group. We employed the chat room discussions during the experiments to study how advice and queries about the appropriate investment strategies affected behavior. Our experimental approach in which chat/observation groups are formed randomly and in which interactions between the individuals of the groups are recorded, allow us to analyze whether a mechanism exists that links health behavior and group communication.

Our experimental design presents two treatments to investigate social impacts on health. In our baseline ***Independent*** treatment, an individual's rewards from investments in life enjoyment depend only on his choices. When rewards are independent of others' choices, individuals do not have monetary incentives to provide any advice. However, individuals still have an incentive to search for advice, and particularly, might be willing to post queries about strategies, hoping that those who perform better will voluntarily provide some guidance. Therefore, in the independent treatment, an individual's willingness to provide advice is mostly generated by their intrinsic motivation to help others.

In the second ***Interdependent*** treatment, rewards not only depend on an individual's choices but also on their similarity to the choices of the others in their group. Individuals have a payoff function that provides them incentive to make behavioral choices similar to the other members of their group (a conformity coefficient). Therefore, in the interdependent treatment, individuals have an extrinsic motivation to discuss, agree, and coordinate on health behavior.

In keeping with the theme of this special issue, the goal of this article is to utilize this experimental design to test a series of hypotheses about social influences on health behavior. We propose that social effects derive from two principle routes. First, people utilize observation of behavior and engage in direct communication about practices and strategies in order to be better able to achieve their goals. Providing advice and educating others is an intrinsically human and pro-social activity. Humans have been providing advice regarding health behavior for millennia (Kleinman 1980), and now they can even provide advice to strangers on the Internet (Constant et al. 1996, Swan 2012). A second route for social effects derives from the increased utility people gain by the extent to which their choices conform to those of others, with whom they interact and identify. This second route may reinforce the optimizing effects of the first route, but may also lead to multiple equilibria. In other words, communication, queries and advice regarding health behavior, can improve health investment and life-enjoyment choices, but also can lead to suboptimal habits. From this logic, we test the following predictions:

1) In both treatments, subjects will make queries and provide strategic advice during chat.
2) Significant chat heterogeneity will exist between groups, above the individual heterogeneity of its members, through processes of observation and information exchange.
3) Advice and queries will be most common during the first few lives of the experiment while individuals are most focused on learning.
4) Due to incentives, chat about investment behavior will be more frequent in the interdependent treatment than in the independent treatment.
5) The conformity payoff in the interdependent treatment will *decrease* within-group variance in behavior.
6) Due to the possibility of multiple equilibria, the interdependent treatment will *increase* among-group variance in behavior.

7) As a result of 5, the worst performing groups, in terms of optimizing investments per period over the life course, will be more common in the interdependent rewards treatment.

## 2. The Health Investment Problem: Theory and Experimental Environment

In the experiments to be reported each individual participant worked in a real effort harvesting task to earn income and made a sequence of investment decisions in a series of unrelated lifetimes. Each lifetime was comprised of a sequence of 9 periods (t =1, 2,…9) of real effort earnings activity followed by investment decision making. Every lifetime ended after nine periods unless the participant's 'health' had degenerated to the point of death before then. After each lifetime ended, every participant was 'reincarnated' into his next unrelated lifetime.

Once the participant finished the real effort harvesting task in period t, from which effort she had secured harvest revenue[1], $R_t$, proportional to current health, she was required to make investment decisions: how much to invest, $I_t$, in preserving health for future harvesting, how much to invest in life enjoyment, $L_t$, in order to be paid for her efforts, and how much (if any) to leave uninvested in a bank account, $B_t$, that would become available for future investments in life enjoyment or health. All participants were endowed with a beginning bank balance, $B_0$, of 0, and should end with a final bank balance, $B_9$, of 0, if

[1] For a complete description of the real effort harvesting task, the revenue possible, and the optimal harvesting strategy see Appendix 1.

they maximize their total gains from life enjoyment. The budget constraints governing investment in each period were given by:

$$I_t + L_t + B_t = B_{t-1} + R_t \quad \forall\ t=1, 2, \ldots 9$$

The non-linear return functions for investments in health and life enjoyment are given below. They were designed to have diminishing returns to scale, so that the optimal investment pattern across time would display properties similar to a Grossman model. The transition equation in our experimental system relating final health in period t ($H_t$) to final health in the previous period ($H_{t-1}$), given an investment ($I_t$) in preserving health, and a natural degeneration ($d_t$) of health that occurred during period t, was given by:

$$H_t = Min\ [100, H_{t-1} - \mathrm{d}_t + 30\frac{1 - e^{-.025\mathrm{I_t}}}{1 + e^{-.025\mathrm{I_t}}}]$$

A participant could theoretically regenerate health by up to 30 points in any given period if she had accumulated an ‘infinite’ amount of harvest revenue to invest, but an upper bound was imposed that prevented the next state of health from ever exceeding 100. Furthermore, the parameters in the experimental environment were chosen such that the boundary condition, $H_{t+1} = 100$, was never approached under optimal or ‘reasonable’ decision making. Given the interior solution was always active, the marginal rate of return on health investment each period was given by:

$$\frac{dH_t}{dI_t} = \frac{1.5e^{-.025\mathrm{I_t}}}{1 + 2e^{-.025\mathrm{I_t}} + e^{-.05\mathrm{I_t}}}$$

Note that at $I_t = 0$, $dH_t/dI_t = 3/8$ and the rate of return on each subsequent revenue unit invested in health is independent of initial state of health ($H_t$) until health reaches 100. Over many periods and lifetimes, participants could become very familiar with the fixed function governing diminishing returns on health investment.

The earnings equation relating investment in life enjoyment ($L_t$) to cash earned ($E_t$) in period t, by a socially independent participant was given by:

$$\text{Socially Independent Earnings: } E_t = 250(1 + H_t/100)(1 - e^{-.028L_t})$$

By convention, in any given period t, degradation of health occurred after harvesting. Then health investment, $H_t$, selected was implemented prior to the life enjoyment investment, $L_t$, so that the upgraded state of health would be incorporated into the life enjoyment computation. The participants were given graphical representations of the health and life enjoyment investments that made it very clear that both had diminishing returns.[2] The participant's job was to correctly balance investment of harvesting revenue between health and life enjoyment, each period of her lifetime. To maximize her earnings across her entire life (periods 1-9) the participant had to solve the following nonlinear program:

Maximize: $\sum_{t=1,9} E_t = \sum_{t=1,9} 250(1 + H_t/100)(1 - \mathrm{e}^{-.028L_t})$

Subject to: $B_{t-1} + R_t = I_t + L_t \quad \forall\, t = 1, \dots 9$

$$H_t = H_{t-1} - \mathrm{d}_t + 30\frac{1-e^{-.025\mathrm{I_t}}}{1+e^{-.025\mathrm{t}}} \quad \forall\, t = 1, \dots 9$$[3]

$R_t = rev(\mathrm{H_t}/100)$ during any active harvest period[4]

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[2] The second derivatives are calculated in the Appendix 2.

[3] Health degeneration $\mathrm{d_t}$= {-16, -17, ... -23, -24}

[4] Rev is a fixed parameter that indicates participant harvesting proficiency. See Appendix 2 for further discussion.

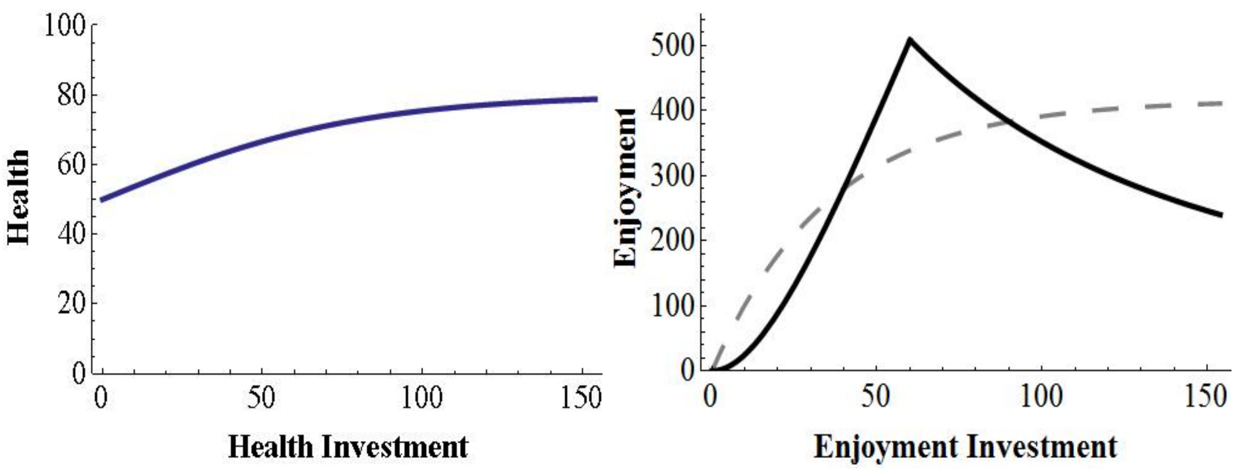
The main treatment variable in the experiments reported determined whether each subject's earnings from investing in life enjoyment were interdependent or independent of the decisions made by other subjects in his social group. The earnings equation for socially interdependent participants, relating investment in life enjoyment ($L_t$) to cash earned ($E_t$) in period t given the mean investment, $O_t$, made by all other subjects in the subject's social group, is given by:

Socially Interdependent Earnings: $E_t = 1.5 * \frac{Min(L_t,O_t)}{Max(L_t,O_t)} * 250(1 + H_t/100)(1 - e^{-.028L_t})$

Note, these earnings were simply computed as the Socially Independent Earnings multiplied by a 'conformity multiplier,' $1.5 * \frac{Min(L_t,O_t)}{Max(L_t,O_t)}$. The ratio $\frac{Min(L_t,O_t)}{Max(L_t,O_t)}$ measures the proportion by which the subject's life enjoyment investment, $L_t$, matches the mean life enjoyment investment, $O_t$, of other members of her social group. Under interdependence, a subject who conforms to the group mean in making her life investment choices could earn a premium of up to 50%, while one that strayed from her group's mean (more than 33% below or above) would find herself earning less than she would if she were not socially bound.

The Health graph below indicates that starting from her current health of 50, the participant could possibly increase her next period's health up to level 80 by making a large health investment. Meanwhile, the Enjoyment graph below shows two lines: the dashed line represents enjoyment earnings under social Independence, while the solid line represents enjoyment earnings under social Interdependence when other members of the subject's group make a mean investment of 60. In experiments where subjects are

Independent they only see the dashed line. In experiments where subjects are Interdependent they see both lines and can adjust the location of the apex of the solid line according to their premonition concerning their group's mean investment. The enjoyment graph shows that under Independence a subject who invests 60 in life enjoyment would receive a payoff of ~333, which would be translated to a cash reward at experiment's end. Under Interdependence if the group mean were 60 and the subject made the same investment, she would earn 500 = 1.5 x 333, while if she chose to invest 40 or 130 she would only earn ~300[5].




In our environments, the shape of the Health investment graph would never alter: only the starting point on the Y-axis, current health, would adjust from period to period. However the shape of the Enjoyment Investment graph would get steeper if health deteriorated or flatten if health improved.

Note that in the constrained dynamic maximization problem the subject must solve, $H_t$ can be rewritten as a function of her initial health, $H_0$, and investments, $I_t$, in health.

[5] In order to make investments, the participant used reciprocating scroll bars on the x-axis of each graph that would not allow her to spend more than the revenue she had accumulated.

$$H_t = H_0 + \sum\nolimits_{k=1,t} -d_k + 30\frac{1 - e^{-.025\mathrm{I_k}}}{1 + e^{-.025\mathrm{I_k}}}$$

So solving the participant's constrained life enjoyment optimization can be rewritten as an unconstrained optimization that is a function of the sequence of health investments $I_i$ and bank deposits $B_t$[6]:

$$\sum_{t=1,9} E_t = \sum_{t=1,9} 250(1 + \left[H_0 + \sum\nolimits_{k=1,t} -d_k + 30\frac{1 - e^{-.025\mathrm{I_k}}}{1 + e^{-.025\mathrm{I_k}}}\right] /100)(1 - e^{-.028(B_{t-1}+R_t-I_t)})$$

This problem is easy to solve numerically for any given period t when $H_{t-1}$, $B_{t-1}$, $R_t$ and $B_t$ are known.[7] The initial conditions for health and bank balance were given by $H_0 = 85$ and $B_0 = 0$, the final bank balance $B_9$ must be zero, and $R_t$ is always a linear function, rev($H_{t-1}$/100), of previous period's health. We can either apply non-linear optimization or dynamic programming techniques to find the optimal sequence of health investments, $I_t$, and the corresponding maximal aggregate life enjoyment $\sum_{i=1,9} E_t$.

It is important to note that under Interdependence, even with its premium for investment conformity and penalty for non-conformity, the optimal investment pattern for like-skilled harvesters is exactly the same as it is under Independence. The best that any group can do

[6] The parameters in the environments we designed were such that the optimal $B_t^*$ was rarely anything other than 0. This considerably reduced the dimension of the decision making problem faced by participants. On rare occasions, during the move from harvesting to retirement (periods 6 to 7), there was a minor improvement in overall life enjoyment by banking some harvest income to smooth investment in life enjoyment.

[7] Appendix 2 provides the example of period 9.

is for all individuals to conform to what would otherwise be the optimal investment pattern for each under Independence: resulting earnings would simply be multiplied by 1.5.

Using $R_t = 87(H_{t-1}/100)$ (we found that 87 was the low variance, mean skill parameter of all participants), the period by period optimal Health ($H_t$) profile that participants should maintain in order to make health investments ($I_t$) that maximize total life enjoyment ($\sum E_t$) is given in the following table:

| Optimal Health ($H_t$) by period: | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 89 | 91 | 92 | 90 | 86 | 78 | 65 | 42 | 18 |

The table below captures a quantitative representation of what is necessary to maintain this optimal health vector, and hints at some behavioral difficulties participants might encounter if their perception of optimal strategy requirements is less than perfect. It shows the marginal rates of return for optimal investments in life enjoyment in each period of life, and implicitly the rate of return on investment in health and banking for current and future enjoyment maximization.[8] It also shows the percentage of income earned (plus banked[9]) that must be devoted to optimal health maintenance in each period of life.

| Optimal Marginal Rate of Return, % of Income Invested in Health, by period: | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 10.0, 86 | 8.6, 80 | 7.4, 73 | 6.3, 67 | 5.3, 59 | 4.3, 50 | 3.3, 35 | 2.5, 0 | 2.5, 0 |

[8] This is true for all periods except where a boundary condition is met (only in periods 8 and/or 9) and the marginal return on any investment in health is dominated by investment in life enjoyment ($L_t$) so the optimal investment in health is zero ($I_t$=0).

[9] There are only 2 periods in the 36 displayed where it behooves subjects to bank some earned revenue for the purpose income smoothing: in period 8 of the Flat No Retirement regime where health will fall precipitously in period 9, and in period 6 of the Tiered Retirement regime where income falls precipitously in period 7, the first period of retirement.

Savvy participants must recognize that 86% of earned revenue from harvesting must be spent on health in period 1, and 80% in period 2, while the marginal rates of return on investments are 4 times larger than later in life: that skewed optimal investment strategy is a requirement to be reckoned with in splitting earned harvest revenues between health and life enjoyment. Late in life (periods 8 and 9), participants must let go of their health and spend entirely on life enjoyment. The complete solution for all decision and state variables are provided in Appendix I.

**Multiple Lives and Chat Groups**

This nine period dynamic optimization problem is difficult to solve, due to the nonlinearities and interactions in the health and life enjoyment functions. In order to allow subjects to learn about the environment and to adjust their strategies accordingly, subjects lived eight nine-period lives under identical conditions. This 'reincarnation' can be thought of as a way of modeling cultural traditions in which individuals learn from previous generations how to best perform in the environment. In addition, we proposed that in response to difficult dynamic problems, people would use observational learning and information exchange to help solve those problems. To model that process, subjects were divided in four-person chat-observation groups. Subjects could observe the behavior of three other subjects (the same three people in each life) and could chat with them, using text messages, between lives.

Under Social Independence the chat group provided nothing more than a venue to exchange information concerning individual strategy, but under Social Interdependence, the mean investment in Life Enjoyment by other members of a chat group became the norm by which investment of each group member was evaluated and translated into earnings. Interdependence allowed conformity in investment strategies to enhance earnings and non-conformity to penalize them. Under Interdependence, chat provided a venue for both optimizing and conforming strategies to evolve.

A total of 156 subjects, who were randomly allocated to 39 chat/observation groups, 68 subjects (17 chat groups) in the Independent treatment, 88 subjects (22 chat groups) in the Interdependent treatment. Members of each chat-group were free to observe and discuss (or not) each other's performances for 90 seconds at the end of each lifetime.

Subjects' conversations were captured by the messages written in chat window. Chat lines were classified independently by two independent research assistants that acted as coders[10]. Coders were trained to apply a classification criterion that captures the presence of strategic advice and queries.

To achieve this goal, coders classified lines into one of four thematic categories and into one of two linguistic categories. The thematic categories captured message's meaning, while the linguistic category captured the message's direction and intention. The four thematic categories were: Income Generation, Income Allocation, Other Experimental Issues, Non-Experimental chat. In this article we focus on the second category: this

[10] The chat lines of the *Independent* treatment were classified by four coders. To be consistent with the classification of chat lines in the Interdependent treatment, we used for this paper a classification based on hose codifiers with similar interelaiability rates to the codifiers of the *Interdependent* treatment.

category includes all those messages in which subjects expressed ideas or concerns regarding the allocation of their income to health and life enjoyment. The two linguistic categories were: Statements or Queries. Chat lines were assigned to particular class only if both coders agreed on their classification.

## 3. Statistical Approach

In order to handle the repeated and clustered nature of the experimental design, we employed a mixed fixed and random effects linear model to analyze the data. Each subject lived eight lifetimes, having the opportunity to chat with others in her chat/observation group seven times. During the experiment, each subject chose 72 times (8 lives x 9 periods) how to allocate her income between health and life enjoyment investments. The empirical model takes into account the lack of independence among observations within and among individuals in groups. To do this, the model estimates the fixed effects of lifetime, experimental treatment, and interaction terms, while assessing the random effects for chat group and individual.

## 4. Results

*Descriptive Statistics*

Descriptive statistics for the main variables to be analyzed are presented in Table 1. For each of the eight 'lives' in the experiment, the table shows the means for total enjoyment purchased and the number of strategic queries and advice made per subject during the rest phase following that life during which chat was allowed. *Total* enjoyment purchased is the sum of the amount purchased in each of the nine periods and is proportional to the actual amount the subject is paid. Those data are presented in three columns. The first column shows the means for the treatment group in which each subject's rewards from investments in life enjoyment are *independent* (that is, the rewards are unaffected by the behavior of other subjects in the chat group). There are two columns for the other treatment group in which rewards are *interdependent*. The first of those columns (column 2) presents the counterfactual independent rewards (for comparability purposes) that the subjects in the interdependent chat groups would have received if their rewards were independent. The second of those columns (column 3) presents the rewards they actually received from their investments, after their interdependence is taken into account through the conformity multiplier. It is evident from the table that for both treatment groups, Total Enjoyment Purchased increases with each life, indicating that their performance increasingly approached the optimal investment profile across lives. It is also evident that subjects in the interdependent rewards treatment group achieved increasingly high levels of conformity across lives to maximize the multiplier on their investments. The regression models discussed below will examine these effects in detail.

Table 1 Descriptive Statistics

| | Total Enjoyment Purchased | | | Strategic Queries | | Strategic Advice | |
|---|---|---|---|---|---|---|---|
| Life | Independent | Interdependent w/o Conformity | Interdependent with conformity | Independent | Interdependent | Independent | Interdependent |
| 1 | 940 | 1050 | 1026 | 0.6 | 2.7 | 2.8 | 8.1 |
| 2 | 1244 | 1303 | 1567 | 0.9 | 2.5 | 2.1 | 11.4 |
| 3 | 1400 | 1436 | 1830 | 0.4 | 2.3 | 1.9 | 8.4 |
| 4 | 1587 | 1543 | 2052 | 0.2 | 2.8 | 1.9 | 7.8 |
| 5 | 1645 | 1557 | 2138 | 0.3 | 1.7 | 1.4 | 6.6 |
| 6 | 1679 | 1645 | 2293 | 0.4 | 1.3 | 1.4 | 5.5 |
| 7 | 1759 | 1633 | 2303 | 0.1 | 1.0 | 1.0 | 5.5 |
| 8 | 1764 | 1705 | 2427 | n/a | | | |

The last four columns of Table 1 gives the descriptive statistics derived from the coding of the chat that occurred during rest phases between lives. In contrast to earnings which increase over the course of the experiment, chat queries and advice about strategy are more frequent following the first few lives, and then decrease. Interestingly, advice is about four times more common than queries. Tables 2 and 3 present the results of mixed effect regression model, with fixed effects for the experimental variables and random effects for individual and chat/observation group variables as explanatory variables of strategic queries and advice, respectively. In both tables, Model I regresses life, experimental treatment (Independent vs Interdependent rewards), and their interaction on strategic chat, while controlling for the random effects of individual subject and chat/observation group. There are strong effects of life and treatment on both queries and advice, and some of the interaction terms are significant as well. The interdependent groups both made more queries and gave more advice than those with independent rewards, as would be expected by the gains from coordination and conformity. Relative to the last lives, strategic chat of both types was greatest early in the experiment when learning and behavior change was greatest.

Table 2 Predictors of Strategic Queries

| | | **Model 1** | | **Model 2** | |
|---|---|---|---|---|---|
| Parameter | df | Estimate | Sig. | Estimate | Sig. |
| Intercept | 274 | .26 | 0.000 | .22 | 0.014 |
| Life 1† | 924 | .41 | 0.000 | .41 | 0.000 |
| Life 2 | 924 | .36 | 0.000 | .36 | 0.000 |
| Life 3 | 924 | .31 | 0.001 | .31 | 0.001 |
| Life 4 | 924 | .43 | 0.000 | .43 | 0.000 |
| Life 5 | 924 | .16 | 0.097 | .16 | 0.097 |
| Life 6 | 924 | .07 | 0.477 | .07 | 0.477 |
| Independent Rewards‡ | 274 | -.25 | 0.036 | -.25 | 0.036 |
| Life 1 * Ind. Rewards~ | 924 | -.26 | 0.071 | -.26 | 0.071 |
| Life 2 * Ind. Rewards | 924 | -.16 | 0.277 | -.16 | 0.277 |
| Life 3 * Ind. Rewards | 924 | -.23 | 0.108 | -.23 | 0.108 |
| Life 4 * Ind. Rewards | 924 | -.4 | 0.006 | -.4 | 0.006 |
| Life 5 * Ind. Rewards | 924 | -.1 | 0.490 | -.1 | 0.490 |
| Life 6 * Ind. Rewards | 924 | .01 | 0.971 | .01 | 0.971 |
| Within Group Rank | | | | .02 | 0.406 |
| Covariance Parameters / Random Effects | | Estimate | Sig. | Estimate | Sig. |
| Residual | | .4 | 0.000 | .4 | 0.000 |
| Chat/obs. Group | | .02 | 0.101 | .02 | 0.104 |
| Subject | | .05 | 0.000 | .05 | 0.000 |

†Life parameters are measure against baseline of Life 7.

‡Interdependent rewards are measured against socially interdependent rewards.

~Interaction terms are measured against baselines of socially interdependent rewards and life 7.

These effects can be seen clearly in Figures 1a and 1b, which plot the expected marginal means derived from the Model 1 regressions presented in Tables 2 and 3, respectively. On average, queries are about five times more frequent and advice is about 4 times more common in the interdependent than independent rewards treatment. This is to be expected, given that advice and queries that increase conformity of investment in life enjoyment have direct monetary payoffs for those in the interdependent rewards treatment. However, it is also interesting to note that in both treatments, advice is about four times more common than are queries. This is particularly interesting in the case of the independent rewards treatment, because subjects do not get any direct monetary benefits from giving advice.

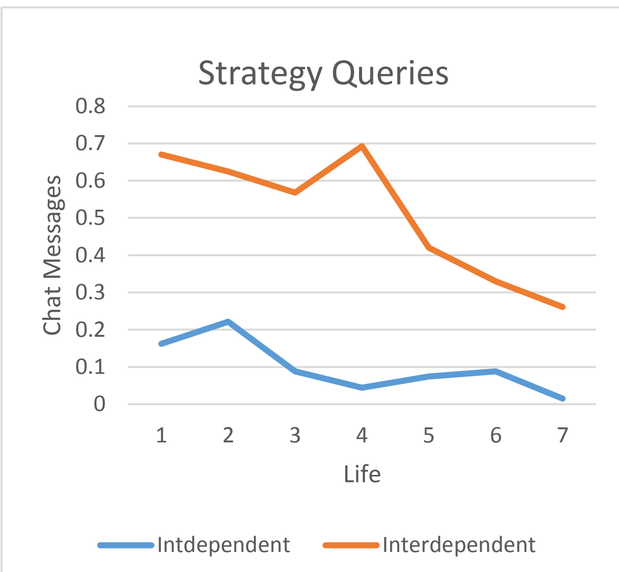


Figure 1a: Model 1, Queries

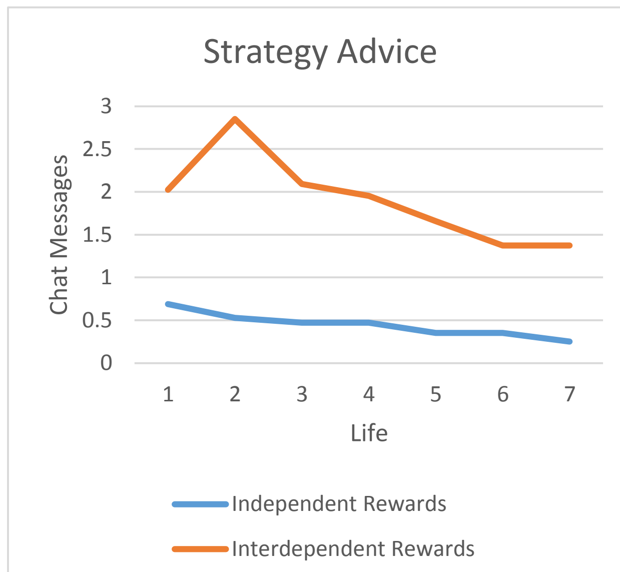


Figure 1b: Model 1, Advice

In both tables, Model 2 adds one additional variable to the base Model 1, within-group earnings rank. This variable, with levels one to four, ranks each of the four members of the chat/observation group in terms of how much they earned in the life previous to that chat session (with one being the highest, and four being the lowest earner). This variable was added to determine whether higher earners were more likely to give advice and lower earners more like to make queries asking for advice. The results show that high earners are more likely to give advice, with advice statements decreasing by about .24 with each successive rank. However, rank did not have a significant effect on queries. It would appear that subjects that did well relative to others whom they could observe and engage in chat were more motivated to offer advice, but asking for advice, which was less common, did not depend on rank.

Table3: Predictors of Strategic Statements

| | | **Model 1** | | **Model 2** | |
|---|---|---|---|---|---|
| Parameter | df | Estimate | Sig. | Estimate | Sig. |
| Intercept | 76 | 1.38 | 0.000 | 1.98 | 0.000 |
| Life 1† | 924 | 0.65 | 0.008 | 0.65 | 0.008 |
| Life 2 | 924 | 1.48 | 0.000 | 1.48 | 0.000 |
| Life 3 | 924 | 0.72 | 0.004 | 0.72 | 0.003 |
| Life 4 | 924 | 0.58 | 0.018 | 0.58 | 0.018 |
| Life 5 | 924 | 0.28 | 0.247 | 0.28 | 0.244 |
| Life 6 | 924 | 0.00 | 1.000 | 0.00 | 1.000 |
| Independent Rewards‡ | 274 | -1.13 | 0.013 | -1.13 | 0.013 |
| Life 1 * Ind. Rewards~ | 924 | -0.21 | 0.578 | -0.21 | 0.576 |
| Life 2 * Ind. Rewards | 924 | -1.20 | 0.001 | -1.20 | 0.001 |
| Life 3 * Ind. Rewards | 924 | -0.50 | 0.182 | -0.50 | 0.180 |
| Life 4 * Ind. Rewards | 924 | -0.36 | 0.334 | -0.36 | 0.331 |
| Life 5 * Ind. Rewards | 924 | -0.18 | 0.626 | -0.18 | 0.624 |
| Life 6 * Ind. Rewards | 924 | 0.10 | 0.782 | 0.10 | 0.780 |
| Within Group Rank | | | | -0.24 | 0.000 |
| Covariance Parameters / Random Effects | | Estimate | Sig. | Estimate | Sig. |
| Residual | | 2.64 | 0.000 | 2.62 | 0.000 |
| Chat/obs. Group | | 1.03 | 0.001 | 1.06 | 0.001 |
| Subject | | 0.71 | 0.000 | 0.60 | 0.000 |

†Life parameters are measure against baseline of Life7

‡Interdependent rewards are measured against socially interdependent rewards

~Interaction terms are measured against baselines of socially interdependent rewards and life 7.

The last set of rows in Tables 2 and 3 present the random effects, the residual unaccounted for variance and the effects due to individual subject and chat group. In the case of queries, there were significant random effects in subject's play, but the effects of chat group were not significant. In the case of strategic advice, both individual and chat group random effects were significant, and in fact, the random effects estimate for chat group were slightly greater than for subject.

Together, these results support predictions 1-4 above: Subjects engaged in helpful chat in both treatments; there was significant heterogeneity among both subjects and groups in chat frequencies; chat was most common early in the experiment; and chat was more frequent in the interdependent treatment.

*Predictors of Enjoyment Earnings and Assessment of Social Effects*

Due to the dramatic differences in chat by treatment and the expectation that the variance within and among chat groups would differ between the two treatments, we analyze the Enjoyment Earnings for the two treatment groups, separately. Tables 4 and 5 present the results of the mixed fixed and random effects regression models for the independent and interdependent rewards treatments, respectively. In Table 4, Model 1 presents the baseline model in which Enjoyment Earnings are regressed on life alone, while Model 2 adds an additional variable, Total Strategic Chat, to the base model. Total Strategic Chat is the sum of both queries and advice statements over all four members of the group following a given life. This variable was added as an attempt to examine whether verbal exchanges over strategy improved earnings in the next life.

For the independent rewards treatment, we can see from the base Model 1 that earnings increase by almost 90% during the course of the experiment from 940 in life 1 to 1764 in life 8. Model 2 shows that Total Strategic Chat did not have a significant effect on earnings. However, the random effects terms do show appreciable group level random effects, suggesting that observing other group members' play and/or the chat did have effects on behavior. Nevertheless, the estimates for random effects at subject's level were a little more than three times as high as for chat groups (35,053 vs. 10,818), as expected for the independent treatment.

Table 5 presents the results of the estimation of the regression models for interdependent treatment, both for the counterfactual earnings without the conformity multiplier and the actual earnings, taken into account the conformity effect. From the Model 1 analysis, we see that earnings also increase from life to life, starting from a mean of 1050 in life 1 and ending with mean of 1704 in life 8 without the conformity multiplier, and from 1026 to 2427 with the multiplier. Adding Total Strategic Chat in Model 2, we see that it has no significant effect on earnings without the multiplier, but a large effect with the multiplier. Taken together, the results in Tables 4 and 5 suggest that we cannot detect an effect of chat on solving the dynamic problem of optimizing investments over the nine-period life course, but we can detect an effect of chat on improving earnings through the conformity multiplier. In other words, subjects were able to coordinate their strategies and make similar investments in each period; the chat appears to have facilitated this coordination.

Table 4 Enjoyment Earnings without Socially Dependent Rewards

| | Model 1 | | | Model 2 | | |
|---|---|---|---|---|---|---|
| Parameter | df | Estimate | Sig. | df | Estimate | Sig. |
| Intercept | 39 | 1764 | 0.000 | 36 | 1761 | 0.000 |
| Life 1 | 469 | -824 | 0.000 | | | |
| Life 2 | 469 | -520 | 0.000 | 407 | -526 | 0.000 |
| Life 3 | 469 | -364 | 0.000 | 405 | -369 | 0.000 |
| Life 4 | 469 | -176 | 0.000 | 403 | -179 | 0.000 |
| Life 5 | 469 | -119 | 0.004 | 402 | -122 | 0.003 |
| Life 6 | 469 | -85 | 0.037 | 402 | -86 | 0.031 |
| Life 7 | 469 | -5 | 0.896 | 402 | -7 | 0.860 |
| theme2_sum | | | | 397 | 2 | 0.638 |
| Covariance Parameters / Random Effects | | Estimate | Sig. | | Estimate | Sig. |
| Residual | | 56204 | 0.000 | | 53691 | 0.000 |
| Chat/obs. Group | | 35053 | 0.000 | | 41606 | 0.000 |
| Subject | | 10817 | 0.167 | | 11095 | 0.199 |

*Table 5 Enjoyment Earnings with Socially Dependent Rewards*

| | Model I | | | | | Model 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Interdependent w/o conformity | | Interdependent with conformity | | | Interdependent w/o conformity | | Interdependent with conformity | |
| Parameter | df | Estimate | Sig. | Est. | Sig. | df | Est. | Sig. | Est. | Sig. |
| Intercept | 39 | 1705 | 0.000 | 2427 | 0.000 | 36 | 1698 | 0.000 | 2390 | 0.000 |
| Life 1 | 469 | -655 | 0.000 | -1401 | 0.000 | | | | | |
| Life 2 | 469 | -402 | 0.000 | -860 | 0.000 | 407 | -406 | 0.000 | -882 | 0.000 |
| Life 3 | 469 | -269 | 0.000 | -597 | 0.000 | 405 | -276 | 0.000 | -639 | 0.000 |
| Life 4 | 469 | -162 | 0.000 | -375 | 0.000 | 403 | -166 | 0.000 | -399 | 0.000 |
| Life 5 | 469 | -148 | 0.000 | -289 | 0.000 | 402 | -152 | 0.000 | -310 | 0.000 |
| Life 6 | 469 | -60 | 0.080 | -134 | 0.006 | 402 | -62 | 0.055 | -143 | 0.002 |
| Life 7 | 469 | -72 | 0.036 | -124 | 0.011 | 402 | -72 | 0.025 | -124 | 0.007 |
| theme2_sum | | | | | | 397 | 1 | 0.473 | 5 | 0.005 |
| Covariance Parameters / Random Effects | | Est. | Sig. | Est. | Sig. | | Est. | Sig. | Est. | Sig. |
| Residual | | 51678 | 0.000 | 102943 | 0.000 | | 45205 | 0.000 | 92560 | 0.000 |
| Chat/obs. Group | | 11533 | 0.000 | 10179 | 0.013 | | 13567 | 0.000 | 14248 | 0.003 |
| Subject | | 42449 | 0.003 | 133297 | 0.002 | | 51138 | 0.003 | 157171 | 0.002 |

Figure 2 illustrates these effects by plotting the expected marginal means for enjoyment earnings from the Model 1 regressions in Tables 4 and 5. Earnings for both treatments increase with each progressive life, and are very similar on average for the two treatments, when the conformity bias is not taken into account. However, the interdependent chat groups also increasingly took advantage of the conformity multiplier (as can be seen by the increasing distance between the red and orange lines).

The dramatic effects of introducing interdependence in rewards can be seen from the variance decomposition of the random effects. As opposed to the independent rewards case where the chat group random effects were one third as large as the individual subject random effects, they were 13 times larger (133,297 vs 10,179) in the case of actual enjoyment earnings in the interdependent case. The ratios of the within and between group variances reverse moving from independent to interdependent rewards. The differences between the two treatments were highly significant ($p < .0001$), for both within-group variance (higher in the independent rewards treatment) and between-group variance (higher in the interdependent treatment).

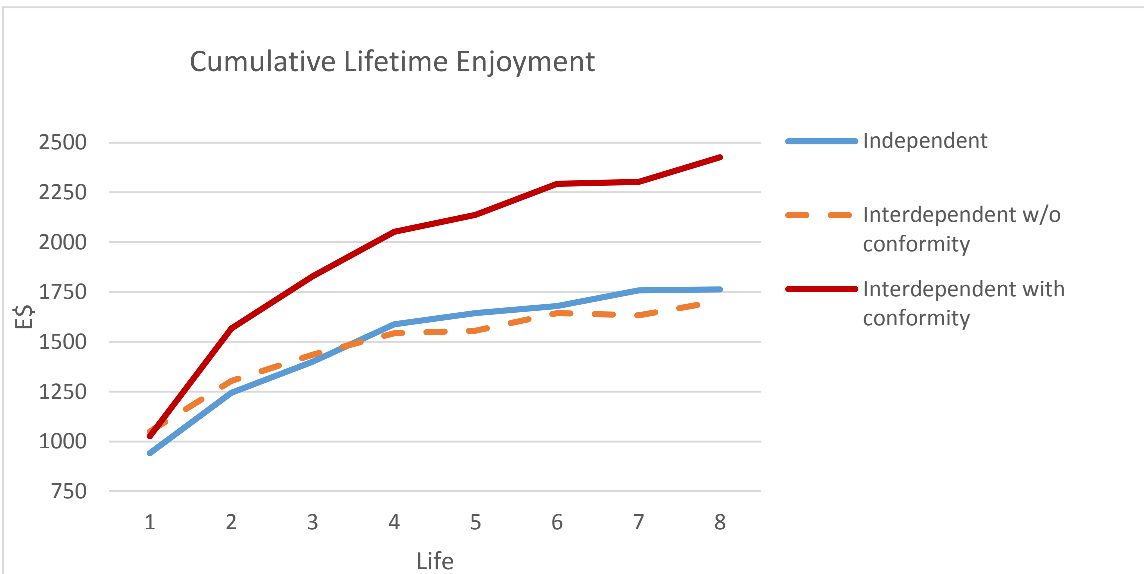



Figure 2: Enjoyment Earnings Marginal Means

Finally, to ask whether the conformity effect might lead some groups to converge on suboptimal strategies, we examined the likelihood of being in the bottom quartile of earnings at the level of the chat group. To make the data comparable, we used the total enjoyment purchased for the groups in each treatment, ignoring the conformity multiplier.

Those results are presented in Table 6, using data from lives 7 and 8 when earnings in both treatments were highest.

*Table 6 Cumulative Earnings in the Lowest Quartile*

| Lowest Quartile Enjoyment Earnings | Treatment Group | | Total |
|---|---|---|---|
| | Independent | Interdependent | |
| No | 30 | 29 | 59 |
| Yes | 4 | 15 | 19 |
| Total | 34 | 44 | 78 |

Table 6 shows that just over a third of the chat groups in the interdependent rewards treatment were in the lowest quartile of mean earnings (15/44), whereas only 11% were in the lowest quartile in the independent treatment, leading to an odds ratio of about 3. These results suggest that the focus on social conformity in investment in life enjoyment can increase variance among groups, with some groups stabilizing at behavioral strategies quite far from optimal dynamic performance.

Together, these results support predictions 5-7 with the interdependent treatment decreasing within-group variance but increasing between-group variance, sometimes resulting in behavior far from the optimum with respect to the dynamic problem.

## 5. Discussion and Conclusions

There are two large scale implications of these findings. First, in keeping with the theme of this special issue, individual incentives explain a large part, but not all, of the variance in prosocial behavior in the form of strategic advice. Second, incentives for conformity promote prosocial behavior, but also increase variance among groups in equilibrium outcomes, leading to convergence on suboptimal strategies for some groups. We discuss each in turn.

The independent rewards treatment provides insights into 'non-selfish' prosocial behavior. In that case, there were no monetary incentives for subjects to help others find the optimal strategy of investments, but there were also no monetary incentives to defect or mislead them. Nor were subjects given instructions about what they could talk about between lives. Nevertheless, about one third of chat messages were about strategies of how to perform in the experiment, two thirds of which were directed to optimal investment (about 2 messages per life). Moreover, most messages were advice rather than queries about strategy. Individual monetary incentives might explain queries, but are less likely to explain advice. In addition, subjects who did relatively better than other in their group in terms of earnings were more likely to provide strategic advice, but were no more likely to make queries. This suggests that better earners were motivated to help those who did worse.

We were unable to show that in the independent rewards treatment, quantity of strategy messages was associated with earnings. There are several possible explanations of this finding. One is that quantity of messages without reference to quality is a poor measure of information flow. This explanation would be consistent with the finding that there were significant random effects of chat groups on earnings, and on both health investments and enjoyment investments. Another possible explanation is that the dynamic optimization problem subjects faced was particularly complex and nonlinear. They showed through their behavior that they were able to improve their performance over time, but it may have been difficult to put those improvements into words in simple chat messages.

The interdependent rewards treatment provided strong monetary incentives for subjects to coordinate on behavior. These motivations resulted in both absolutely more strategy chat and a greater relative emphasis on strategy than on other topics. People in the interdependent group sent about four times as many strategy messages as the independent rewards group, but they sent fewer messages about topics outside the experiment (1.2 versus 3 messages on average per life per chat group). Just as in the independent treatment, higher earners (relative to other chat group members) in the socially dependent treatment offered more strategic advice than lower earners, and advice was much more common than queries.

With respect to the impacts of chat on earnings, we found mixed results for the interdependent treatment. As in the case of the independent rewards, we found no significant effects of chat on earnings without taking into account the conformity multiplier. However, actual earnings, taking into account the multiplier, were positively associated with the number of strategy chat messages sent in a life. One interpretation of this finding is that the chat served more to facilitate conformity on one strategy, rather than to optimize investments over the life course. Figure 3 examines this possibility by comparing observed investment behavior with optimal investment behavior. A visual inspection of the figure suggests that subjects in the independent rewards treatment converged more on the optimal strategy on average than those in the interdependent treatment. Unlike the theoretical optimum, investments in life enjoyment in the interdependent treatment tend to remain flat rather than increase throughout life, and investments in health decrease much less than is optimal. This suggests that subjects may have converged on rules of thumb that were easily transmissible. Also, in support of this interpretation that conformity can conflict with optimizing are (1) the increasing divergence of the actual earnings from earnings without the multiplier in Figure 2; and (2) the increased likelihood of being in the bottom quartile of earnings for subjects in the socially interdependent treatment, when the conformity bias is not taken into account.

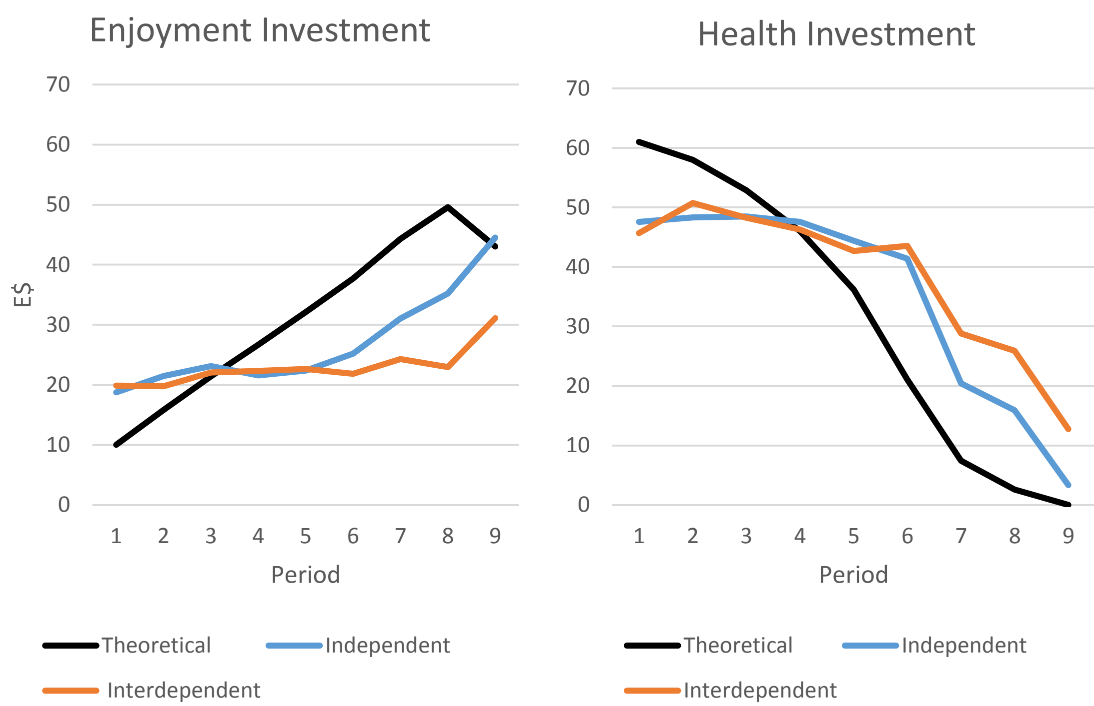



Figure 3. Observed and Theoretically Optimal Investment strategies.

This last finding, when coupled with the massively greater random effects at the chat group level for the socially interdependent treatment than for the independent rewards treatment, may imply that conformity biases can compete with other strategic problems individuals face. In the face of uncertainty, doing what most others do (positive frequency dependent modeling) can often be the best strategy, since it integrates information across individuals and over time (Boyd and Richersen 1988). Moreover, activities that provide enjoyment utility at a potential cost to health, such as smoking, alcohol consumption, and excessive eating, are often done in social contexts. Thus, the variant individual who chooses to avoid those activities and invest in health will forego opportunities for social exchange at the same time.

This tension between gains from conformity and individual optimization may help explain the striking variability in health behavior across regions, ethnic groups and socioeconomic strata. The social costs and benefits of cigarette smoking, alcohol consumption, physical exercise, and eating patterns are likely to vary with respect to their frequency in the networks in which individuals are embedded. From a social perspective, overweight or over-exercise, for that matter, may be relative terms.

The processes generating varying social equilibria in health behavior and status merit further investigation. Behavioral economic experiments that focus on the interplay of dynamic optimization problems and social forces are likely to provide new insights into why so many different equilibria are observed, and may be particularly productive in explaining changing patterns of health.

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## Appendix 1: Real Effort Harvesting

During the first part of each period in each life, participants were required to undertake a real-effort harvesting task in which the participant could earn revenue, $R_t$, that she could subsequently invest in either life enjoyment (a cash reward) or health preservation for subsequent periods of the current lifetime. The amount of time allowed for the harvesting task during each period (maximum 30 seconds) was directly proportional to the participant's current level of health, $H_t$, (between 0 and 100), so investment in upgrading health enabled a higher levels of harvesting in future periods. The initial health condition, 85, and the natural degeneration of health across all periods of life {-16, -17, … -23, -24} were preprogrammed and identical for all participants in all lifetimes in all experimental treatments. The health degeneration occurred after harvesting just before investment for the current period began. Never investing in health would result in the participant dying (not being able to continue to harvesting and investing) in period 5.

The harvesting task assigned to participants required vigilance and some manual dexterity but was designed so that most participants could perform at a high enough level that their harvest earnings and optimal investment strategies would be quite comparable. The task involved a sequence of 30 targets that would skirt across a circular harvesting field. Each target had a one of four different harvest values, and each target took two seconds to skirt across the field, after which it disappeared. To harvest the target the participant simply needed to click on the harvesting field while that target was viable. Once a click was made it would take 2 seconds to process the harvested target during which time the participant could harvest no other targets although she could see the unavailable targets as they skirted by. If the participant's current health were at level $H_t \in [0,100]$, then during the first

30x(100- $H_t$)/100 seconds of the harvest period she would see targets go by that she was unable to harvest due to her deteriorated health. Similarly, if a target were only partially processed by the end of the previous period, processing would complete at the beginning of the next period adding a small increment to any downtime due to deteriorated health.

The table below shows the target values available for harvest during each period of each life, and the probabilities that each target would be the next to arrive. The optimal harvesting strategy was simply to harvest either the three most valuable targets whenever one became available and always ignore lower valued targets. If the participant implemented the optimal harvesting policy during any particular harvesting period t, and had a current health level of $H_t$, then $R_t$* was her expected optimal harvesting revenue.

| **Period Target Vector** | **Target Probabilities** | **Expected Income** |
|---|---|---|
| {13*, 10*, 8*, 6} | {.22, .29, .31, .18} | $R_t$* = 94 ($H_t$/100) |

For any given 30 second period the actual harvest revenue can vary slightly about $R_t$* even if the optimal harvesting policy is applied, depending upon the random arrival sequence of the various targets. Furthermore, the skill level (hand eye coordination and required vigilance) of any participant in applying the optimal harvesting policy can reduce the expectation of revenue from harvesting. A perfectly skilled harvester who has a particular proportion, $H_t$/100, of harvesting time available in a given harvesting period because of his current health, collects expected revenues rev ($H_t$/100) where rev = 94. Because the revenues collected from harvesting become income available to invest in health and life enjoyment, lesser harvesting skill, rev < 94, can have a significant effect on the optimal investment plans for participants of varying skill.

To compute the optimal harvesting strategy, consider, for example, the target set V= {13, 10, 8, 6} where the probability of encountering each target type during the next second is given by p={.22, .29, .31, .18}. Given it takes 2 seconds of handling time to process any target, the harvest value per second for each type of target is given by V/2 = {6.5, 5, 4, 3}. The total value per second derived by harvesting only the n most valuable targets is given by $\sum v_i p_i$ = {2.86, 5.76, 8.24, 9.32}. The total handling time for the n most valuable targets is given by $1+ \sum 2p_i$ = {1.44, 2.02, 2.64, 3}. And finally, the total value per second of total handling time is given by $\sum v_i p_i / (1+ \sum 2p_i)$ = {1.99, 2.85, 3.12, 3.1}. The optimal harvesting policy is to always take whichever of the first three targets shows up next. In a 30 second harvesting period this policy would generate a total harvest value of 30 x 3.12 = 94 units of value.

The parameters in the experiment are set such that rev= 94 is the expected revenue per period for a perfectly skilled harvester who is 100% healthy. In the experiments reported, the participants displayed mean harvesting skills that were less than perfect (rev= 87), but with low variance. Because the revenues $R_t$ collected from harvesting become the income available to invest in health and life enjoyment, lesser harvesting skill can have a significant effect on the optimal investment schedule. We use rev= 87, the mean harvesting skill of all subjects,  as the baseline parameter for computing optimal investment planning throughout this paper.

## Appendix 2: Computation

The transition equation relating health at the end of period t to health at the end of period t-1 is given by:

$$H_t = Min\ [100, H_{t-1} - \mathrm{d}_t + 30\frac{1 - e^{-.025\mathrm{I_t}}}{1 + e^{-.025\mathrm{I_t}}}]$$

The first derivative of health w.r.t. investment in health is given by:

$$\frac{dH_t}{dI_t} = 30 \cdot .025e^{-.025\mathrm{I_t}}\left[\frac{1}{1 + e^{-.025\mathrm{I_t}}} + \frac{(1 - e^{-.025\mathrm{I_t}})}{(1 + e^{-.025\mathrm{I_t}})^2}\right]$$

or,

$$\frac{dH_t}{dI_t} = \frac{1.5e^{-.025\mathrm{I_t}}}{1 + 2e^{-.025\mathrm{I_t}} + e^{-.05\mathrm{I_t}}}$$

The second derivative of health w.r.t. investment in health is given by:

$$\frac{d^2H_t}{dI_t{}^2} = 1.5\left[\frac{-.025e^{-.025\mathrm{I_t}}}{1 + 2e^{-.025\mathrm{I_t}} + e^{-.05\mathrm{I_t}}} + \frac{.05(e^{-.025\mathrm{I_t}})(e^{-.025\mathrm{I_t}} + e^{-.05\mathrm{I_t}})}{(1 + 2e^{-.025\mathrm{I_t}} + e^{-.05\mathrm{I_t}})^2}\right]$$

or,

$$\frac{d^2H_t}{dI_t{}^2} = 1.5\left[\frac{-.025e^{-.025\mathrm{I_t}} - .05e^{-.05\mathrm{I_t}} - .025e^{-.075\mathrm{I_t}}}{(1 + 2e^{-.025\mathrm{I_t}} + e^{-.05\mathrm{I_t}})^2} + \frac{.05(e^{-.05\mathrm{I_t}} + e^{-.075\mathrm{I_t}})}{(1 + 2e^{-.025\mathrm{I_t}} + e^{-.05\mathrm{I_t}})^2}\right]$$

$$\frac{d^2H_t}{dI_t{}^2} = -.025\left[\frac{e^{-.025\mathrm{I_t}} - e^{-.075\mathrm{I_t}}}{(1 + 2e^{-.025\mathrm{I_t}} + e^{-.05\mathrm{I_t}})^2}\right]$$

The consumption function which gives subject earnings, $E_t$, from life enjoyment in period t as a function of the portion of harvest and retirement returns that are invested in life enjoyment, $L_t$, is given by:

$$E_t = 250(1 + H_t/100)(1 - e^{-.028L_t})$$

The first derivative of life enjoyment w.r.t. investment in life enjoyment is given by:

$$\frac{dE_t}{dL_t} = 7(1 + H_t/100)(e^{-.028L_t})$$

The second derivative of life enjoyment w.r.t. investment in life enjoyment is given by:

$$\frac{d^2E_t}{dL_t^{\ 2}} = -.196(1 + H_t/100)(e^{-.028L_t})$$

The final period (9) life enjoyment optimization problem is given by: (note that $E_9$ is a function of the final period investment decisions, $I_9$ and $L_9$, and several pre-determined parameters, $B_8$ (what's remaining in the bank after the previous period 8) and $R_9$ (returns from harvesting or retirement in current period 9) and $d_9$ (degeneration of health (=24) that occurs in current period 9 before investing)

Maximize: $E_9 = 250(1 + H_9/100)(1 - e^{-.028L_9})$

Subject to: $B_8 + R_9 = I_9 + L_9$

$H_9 = H_8 - \mathrm{d}_9 + 30\frac{1-e^{-.025\mathrm{I}_9}}{1+e^{-.025\mathrm{I}_9}}$

Which is equivalent to maximizing the unconstrained function of $I_9$:

$$E_9 = 250(1 + (H_8 - \mathrm{d}_9 + 30\frac{1 - e^{-.025\mathrm{I}_9}}{1 + e^{-.025\mathrm{I}_9}})/100)(1 - e^{-.028(B_8+R_9-I_9)})$$

Taking the first order condition with respect to final health investment, $I_9$, and setting equal to 0 we get:

$$\frac{dE_9}{dI_9} = 0 = 250(100 + H_8 - \mathrm{d}_9 + 30\frac{1 - e^{-.025\mathrm{I}_9}}{1 + e^{-.025\mathrm{I}_9}})/100)(-.028e^{-.028(B_8+R_9-I_9)} + 75(\frac{.025e^{-.025\mathrm{I}_9}}{1 + e^{-.025\mathrm{I}_9}}$$

$$+ \frac{.025e^{-.025\mathrm{I}_9}(1 - e^{-.025\mathrm{I}_9})}{(1 + e^{-.025\mathrm{I}_9})^2})(1 - e^{-.028(B_8+R_9-I_9)})$$

$$\frac{dE_9}{dI_9} = 0 = 2.5(100 + H_8 - \mathrm{d}_9 + 30\frac{1-e^{-.025\mathrm{I}_9}}{1+e^{-.025\mathrm{I}_9}})(-.028e^{-.028(B_8+R_9-I_9)}) + 75(\frac{.025e^{-.025\mathrm{I}_9} + .025e^{-.05\mathrm{I}_9}}{(1+e^{-.025\mathrm{I}_9})^2} + \frac{.025e^{-.025\mathrm{I}_9} - .025e^{-.05\mathrm{I}_9})}{(1+e^{-.025\mathrm{I}_9})^2}) (1 - e^{-.028(B_8+R_9-I_9)})$$

$$\frac{dE_9}{dI_9} = 0 = 2.5(100 + H_8 - \mathrm{d}_9 + 30\frac{1-e^{-.025\mathrm{I}_9}}{1+e^{-.025\mathrm{I}_9}})(-.028e^{-.028(B_8+R_9-I_9)}) + 150\frac{.025e^{-.025\mathrm{I}_9}}{(1+e^{-.025\mathrm{I}_9})^2} (1 - e^{-.028(B_8+R_9-I_9)})$$

Letting $d_9 = 24$, we get:

$$0 = (190 + 2.5H_8 + 75\frac{1-e^{-.025\mathrm{I}_9}}{1+e^{-.025\mathrm{I}_9}})(-.028e^{-.028(B_8+R_9-I_9)}) + \frac{3.75e^{-.025\mathrm{I}_9}}{(1+e^{-.025\mathrm{I}_9})^2} (1 - e^{-.028(B_8+R_9-I_9)})$$

$$0 = (190 + 2.5H_8)\left(1+e^{-.025\mathrm{I}_9}\right)^2 - 2.1\left(e^{-.028(B_8+R_9-I_9)}\right)\left(1-e^{-.05\mathrm{I}_9}\right) + 3.75e^{-.025\mathrm{I}_9}(1 - e^{-.028(B_8+R_9-I_9)})$$

The result is a single variable equation in $I_9$ that is soluble by a simple univariate search procedure given the state of the participant ($B_8$, $H_8$, $R_9$) before her optimal investment decision $I_9^*$ is made. $R_9$, harvest revenue is simply a linear function of health in previous periods, either $rev_c H_8$ or $rev_c(H_1+H_2+H_3+H_4+H_5+H_6)/6$ where $rev_c$ is a constant dependent on the target set available. Clearly, $L_9^* = B_8 + R_9 - I_9^*$

The following tables provide the complete optimal decision trajectory for decision makers who are perfect harvesters (rev= 94, given the experiment parameters), and the optimal decision trajectory for decision makers who possess the average harvesting skill (rev= 87) that was demonstrated by our experimental subjects.

| Independent | | | | | | | | Harvest Rate Per Health = 0.94 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Investment Health | 85 | 69 | 72.7 | 75.1 | 75.9 | 74.7 | 71.1 | 64.3 | 52.8 | 33.6 |
| End Health | 85 | 89.7 | 93.1 | 94.9 | 94.7 | 92.1 | 86.3 | 75.8 | 57.6 | 33.6 |
| Harvest | 0 | 79.9 | 84.3 | 87.5 | 89.2 | 89 | 86.6 | 81.2 | 71.3 | 54.2 |
| Health Investment | 0 | 68 | 66.1 | 63.3 | 59.1 | 53.2 | 44.6 | 32.3 | 12.9 | 0 |
| Life Investment | 0 | 11.9 | 18.2 | 24.2 | 30.1 | 35.9 | 42 | 48.9 | 58.4 | 54.2 |
| Cash On Hand | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Life Enjoyment | 0 | 202.3 | 289.3 | 359.7 | 415.5 | 456.5 | 483.1 | 491.5 | 475.8 | 391.1 |
| Marginal ROR | | 9.51 | 8.12 | 6.93 | 5.86 | 4.92 | 4.02 | 3.13 | 2.15 | 2.05 |
| % Invest in Health | | 85 | 78 | 72 | 66 | 60 | 52 | 40 | 18 | 0 |

| Interdependent | | | | | | | | Harvest Rate Per Health = 0.87 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Investment Health | 85 | 69 | 71.9 | 73.3 | 72.9 | 70.4 | 65.1 | 56.1 | 41.7 | 17.7 |
| End Health | 85 | 88.9 | 91.3 | 91.9 | 90.4 | 86.1 | 78.1 | 64.7 | 41.7 | 17.7 |
| Harvest | 0 | 74 | 77.3 | 79.4 | 80 | 78.6 | 74.9 | 67.9 | 56.3 | 36.3 |
| Health Investment | 0 | 63.9 | 61.5 | 58.1 | 53.2 | 46.5 | 37.2 | 23.6 | 0 | 0 |
| Life Investment | 0 | 10 | 15.8 | 21.4 | 26.7 | 32.1 | 37.7 | 44.3 | 49.6 | 43 |
| Cash On Hand | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.7 | 0 |
| Life Enjoyment | 0 | 173.7 | 256.5 | 323.9 | 376.2 | 414 | 435.5 | 439 | 398.9 | 309 |
| Marginal ROR | | 9.99 | 8.60 | 7.38 | 6.31 | 5.30 | 4.34 | 3.33 | 2.47 | 2.47 |
| % Invest in Health | | 86 | 80 | 73 | 67 | 59 | 50 | 35 | 0 | 0 |