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Assisted savings for retirement: An experimental analysis[☆]

Clement E. Bohr[a], Charles A. Holt[b,*], Alexandra V. Schubert[c]

[a] Department of Economics, Northwestern University, USA
[b] University of Virginia, Department of Economics, Charlottesville, VA 22903, USA
[c] Department of Economics, University of Zurich, Switzerland

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ABSTRACT

This paper evaluates the benefit of a basic retirement savings program. It considers a life-cycle experiment with interest paid on a safe asset and returns on a risky asset that induce a stationary fundamental value. The private savings treatment provides an income stream that terminates at retirement. Observed consumption starts too high and finishes low in later periods. The assisted savings treatment smooths income over all periods, which dampens asset price bubbles and improves consumption profiles. This improvement persists in treatments done without asset trading, but disappears with sharply reduced interest rates that simplify present value considerations.

1. Introduction

The recent increase in life expectancies has highlighted the importance of savings for retirement in order to maintain an appropriate, stable standard of living. In countries where government-provided retirement benefits are relatively small like the United States, a high proportion of working adults are not well-prepared for this stage in their lives. For instance, a U.S. survey conducted by GoBankingRates (Kirkham, 2016) reports that 56 percent of respondents across all ages have less than $10,000 saved for retirement, and more than 25 percent of those aged 55 and above have no retirement savings at all. A Merrill Edge (2016) study reported that about 40 percent of non-retirees doubted they would be able to reach the savings level necessary for a comfortable retirement. Even more striking is the fact that 17 percent said they would have to win the lottery in order to reach their retirement goals.[1]

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* Corresponding author.
E-mail addresses: cah2k@virginia.edu, holt@virginia.edu (C.A. Holt).

[1] One may argue that ultimately what matters is the level of happiness during retirement and that a drop in income does not necessarily imply that people will be worse off. Consistent with the psychological hypothesis that humans quickly adjust to negative shocks, Loewenstein, Prelec, and Weber (1999) report no drop in subjective well-being due to retirement, nor was being retired a significant predictor of money anxiety. However, the authors

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These observations stand in contrast with higher savings rates in most European countries, many of which also have generous government-funded retirement programs. The income smoothing induced by some northern European retirement systems is the motivation for the primary treatment in the laboratory experiment reported in this paper. A second set of treatments is used to evaluate factors that influence suboptimal savings in the experiment. Over-consumption and inadequate savings are commonly observed in laboratory and observational studies, and several types of biases have been identified as potential contributors to the problem. This study will focus on the effects of two such biases, namely exponential growth bias and bounded rationality. Exponential growth bias describes the failure to fully understand the extent of the exponential growth of savings. This will result in overconsumption early in the life cycle and with inadequate consumption levels towards the end (Levy and Tasoff, 2016). Bounded rationality is a more general characterization of people's limited cognitive ability. Most people have a difficult time conceptualizing and solving dynamic consumption problems, especially in complex, shifting environments. Social learning from observing others and from one's own experience in previous "lives," however, can result in significant improvements in consumption profiles (Brown et al., 2009). Hence, bounded rationality is an umbrella term, which encompasses exponential growth bias. Though other biases have shown to be significant contributors to the problem of under-saving, they are either not naturally present in a laboratory setting or not relevant to our study.[2]

This paper uses a laboratory experiment to control for factors like retirement duration and consumption preferences to identify suboptimal consumption patterns. The experimental treatments are motivated by the difference between the generous government retirement programs provided in many European countries and the relatively small benefits provided by the U.S. Social Security retirement program. Subjects in the experiment receive an exogenous, flat pre-retirement income stream, and consume by converting cash into "take-home pay," subject to diminishing returns. In addition to making these consumption decisions each period, subjects can trade shares of an asset that pays dividends at the end of each period. They also earn interest on savings in a safe cash account. Participants are assigned to be in one of two treatment groups. In the private savings (PS) treatment, retirement income consists of accumulated cash savings. In contrast, the assisted savings (AS) treatment automatically sets aside a certain amount of cash each period (earning interest). This generates a lower income trajectory that is maintained at a constant level over all periods, including retirement. These experimental treatments were repeated in two simpler settings: one with no asset market trading, and one with no asset trading and a reduced, minimal interest rate. Our main results pertain to the cross-treatment effects between PS and AS. We find that private savings are less than 50 percent of optimal levels for both treatments when subjects face 5% interest and an asset market. As expected, individuals save less in the presence of assisted savings. However, the reduction is only partial in the sense that total lifetime consumption measures are higher with assisted savings. Asset price bubbles are prevalent and are higher in the private savings treatment in which subjects maintain larger cash balances. Our secondary results consider the simplified experimental settings. We find that exponential growth bias is a main contributor to the suboptimal savings behavior. Removing the asset market from the experiment yielded only slightly higher lifetime consumption measures while the effect of assisted savings remained just as prominent. However, sharply reducing the interest on savings significantly increased lifetime consumption measures for the private savings treatment, and thereby eliminated the relative performance improvement associated with assisted savings.

The first section provides a derivation of optimal consumption decisions and equilibrium asset prices. Asset shares are redeemed at fundamental value (present value of "future" dividends) in the final period, which results in theoretical predictions that are flat, independent of time. The experiment procedures and results are presented in the second and third sections. The fourth section presents a follow-up comparison of private and assisted savings in the simplified environments, i.e. in the absence of asset market trading and in the context of a sharply reduced interest rate on cash.

2. Theory: consumption, savings, and asset pricing

The model consists of a sequence of T market periods, each preceded by consumption and investment decisions. Individuals receive exogenous incomes at the beginning of each period, and they also earn money from dividends paid on asset "shares" and from interest paid on money deposited in a safe account. There is an incentive to smooth consumption, induced by an increasing, concave function $u(c_t)$ of the agent's expenditure on consumption, c_t, where agent-specific superscripts on

acknowledge that the results may not be representative of the entire population as subjects are, on average, more affluent. Furthermore, the 1990s featured high returns to those savings vehicles typically used by retirees such as real estate and stock funds. This added monetary boost may have further mitigated financial worries in the survey. More recently, the importance of inducing adequate retirement savings is driven by the prevalence of low interest returns to savings and projected increases in the proportions of over-65 individuals in the U.S. and developed countries (Ortman et al., 2014).

[2] Three important biases not discussed in this study are present bias, debt aversion, and misperceived survival rates. Present bias refers to a preference for consuming earlier rather than later. It is evident that it would be suboptimal for someone with a very strong preference for present consumption to build large savings balances. Debt aversion has more of an effect if income is increasing. Meissner (2016) considers a situation in which subjects are allowed to borrow to make up for asymmetric income streams. When income levels increase over time, participants do not borrow enough to smooth consumption, and when incomes decrease over time, they consume too much (and do not save enough). However, Eckel et al. (2007) use a mix of survey and risk measures to infer that debt aversion has little impact on the take-up of educational loans. Moreover, high credit card, housing, and student loan debts might be driven by speculative motivations (housing) or visceral "gut" motives (credit card purchases), which are not present in standard laboratory experiments, with the exception of Brown et al. (2009) who used payoffs in terms of soda drinks. Third, Groneck et al. (2017) find evidence for misperceived survival rates in that young people save too little because they underestimate how long they will live. In contrast, the old overestimate how much time they have left to live, and consequentially oversave.

these and other variables are suppressed for notational simplicity.[3] The consumption function specifies the rate at which subjects in the experiment can convert lab dollars into "take-home" cash earnings. The analysis of optimal consumption and investment decisions relies on an idealized assumption of perfect foresight about future incomes and share prices.

Each person begins each period, $t=1 \ldots T$, with the receipt of an exogenous income, y_t, and an endogenous income consisting of interest paid on cash and dividends on asset shares held at the end of the previous period. Let prior cash and share holdings be denoted by b_{t-1} and s_{t-1} respectively, with non-negative initial cash, $b_0 \geq 0$, and endowed asset shares, s_0. The per-share dividends and the interest rate, denoted by D and r respectively, are assumed to be constant. With this notation, the beginning-of-period income from all sources is: $y_t + s_{t-1}D + (1+r)b_{t-1}$, which can be used for current consumption or purchases of shares, with the residual going into an account with a safe return of r per dollar deposited. The inter-period linkages can be seen clearly in terms of budget constraints for consecutive periods, which require that:

$$c_t = y_t + s_{t-1}D + (1+r)b_{t-1} - p_t(s_t - s_{t-1}) - b_t \tag{1a}$$

$$c_{t+1} = y_{t+1} + s_tD + (1+r)b_t - p_{t+1}(s_{t+1} - s_t) - b_{t+1} \tag{1b}$$

where the final two terms in each equation are the net expenditures on shares and the residual amount invested in the safe account. The terminal period, denoted by $T+1$, is one in which there is no exogenous income, and the consumption expenditure is the sum of cash held at the end of period T and a known redemption value V for all shares held at that time. Therefore, all cash held at the beginning of period $T+1$ (left over or from share redemptions) is consumed, so no interest and dividend payments are received in that period.

Optimal behavior involves maximization of the sum of induced consumption utilities:

$$\max_{\{s_t, b_t\}} \sum_{t=1,..T+1} u(C_t) \tag{2}$$

subject to the budget constraint (1), initial share endowments, s_0, and the various boundary conditions: $b_0 = 0$, $y_{T+1} = 0$ (no income when shares are redeemed), $s_{T+1} = 0$ and $p_{T+1} = V$ (all shares are redeemed for V in the terminal period), and $b_{T+1} = 0$ (all cash is consumed at the end).

Discounting is induced by a basic economic incentive: any given amount of cash today is worth more than an equal amount in the future since current investments yield interest in the future. This is the incentive that underlies the theory of time discounting, and it is natural to implement this same incentive in the lab. Notice, in particular, that there is no discounting of "future" consumption in (2), as would have resulted from fixed termination probabilities in each period for example.[4] In contrast, all consumption utilities are paid at the end of the laboratory session, so any discounting at this level would involve irrational undervaluing of "later" cash receipts that will be paid to the subject at the same time. Of course, one plausible deviation from rationality would involve a "present bias" which could be due to visceral, instinctual motives.

After substitution of the budget constraints (1) into the utility function (2), the number of shares held after the market clears, s_t, appears in consecutive terms of the utility sum, one for the purchase and one for the next period benefit from the dividend and the subsequent share value, p_{t+1}. Therefore, the derivative with respect to s_t has two terms, which can be equated to 0 to obtain:

$$-p_t u'(c_t) + (D + p_{t+1})u'(c_{t+1}) = 0. \tag{3}$$

Here, the marginal utility loss associated with the purchase of a share in period t must equal the marginal utility gain in the next period as a result of the share value and the dividend (dividends will be deterministic in the experiment). Similarly, the first-order condition associated with the safe asset account b_t requires that the loss in marginal utility from putting a dollar in the safe account equals the subsequent utility gain from the principal and interest:

$$-u'(c_t) + (1+r)u'(c_{t+1}) = 0. \tag{4}$$

Eqs. (3) and (4) combined can be expressed as a difference equation that determines the evolution of the price of the risky asset as a function of the dividend and interest rate:

$-p_t + (D + p_{t+1})/(1+r) = 0$. There exists a flat price sequence, $p_{t+1} = p_t = p$, that solves this difference equation such that

$$p_t = D/r \text{ for all } t. \tag{5}$$

Thus the existence of a safe alternative requires that the foregone interest for purchasing a share in period t must equal the dividend received at the end of the period ($rp_t = D$). An equivalent statement is that the rates of return for the risky and

[3] Crockett et al. (2019) ran some sessions with a concave utility function and others with a linear function. About 80% of the subjects exhibited consumption smoothing with the concave treatment, as compared with only 2% in the linear treatment. There was no risk-free asset, and subjects were forced to consume all money not invested in risky assets. Halim et al. (2016) and Asparouhova et al. (2016) also effectively induced consumption smoothing preferences by making the "take-home pay" depend entirely on consumption in a randomly determined final period.

[4] The classic Hey and Dardanoni (1988) study of consumption behavior induced present value considerations by using *both* interest on cash and a fixed probability (1/10) of ending after each period. They concluded that subjects tended to misperceive the independence of termination probabilities, which generated unpredicted time dependencies and insensitivity to discounting generated by a random device.

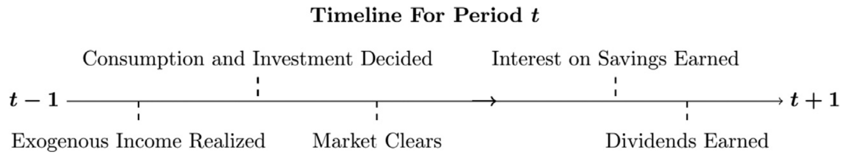

Fig. 1. Timeline of events in a single period.
Note: A period consists of two parts. In the first part subjects receive exogenous income after which they simultaneously make their consumption choices and submit their buy/sell orders. The market then clears at a uniform price and trades occur. In the second part of the period, interest is paid on leftover cash savings, followed by the dividends on shares held after trade. Note that the final period 19 is different in that all shares are redeemed for their fundamental value and redemptions consumed, along with leftover savings.

safe assets are equal in the sense that the ratio of the dividend to the share price of the risky asset must equal the interest rate: $D/p_t = r$. The right side of (5) is the present value of an annuity that pays D in each period over an infinite horizon, using a discount rate of $(1+r)^{-t}$. With a finite horizon, a flat fundamental value price process requires that the final period redemption value be set at this level ($V = D/r$) to avoid "end point effects."[5,6]

The first-order conditions (3) and (4) hold for any initial cash and share endowments, so they would hold during a series of markets in which dividends and trading activity are changing cash and share positions. As would be expected given the incentive for subjects to invest and accumulate wealth, the basic Euler equation displayed in (4) implies that the consumption profile should increase over time. To see this, note that it can be expressed as:

$$u'(c_{t+1})/u'(c_t) = 1/(1+r). \tag{6}$$

The right side is less than 1 since $r > 0$, so $u'(c_{t+1}) < u'(c_t)$. It follows from the assumed concavity of the consumption function (diminishing marginal utility) that $c_{t+1} > c_t$ for all t, irrespective of the time profile of income payments. The CRRA utility function used in the experiment is $u(c) = (\frac{3}{2})c^{2/3}$, for which the ratio of derivatives on the left side of (6) is the cube root of c_t/c_{t+1}. In this case consumption grows geometrically: $c_{t+1} = (1+r)^3 c_t$.

3. Experiment procedures

Overall, the first experimental comparison to be discussed involved twelve markets, six per treatment. There were 18 decision periods in each market, followed by a 19th period in which shares were redeemed and all leftover cash was consumed. At the beginning of the first period, each subject was endowed with six shares that pay a fixed $1 dividend at the end of each period, including the final period, after which the share would be redeemed for $20. In addition, at the start of each period participants received an exogenous income that was announced in advance. In the retirement or "private savings" (PS) treatment, subjects received an income of $100 for the first 14 periods, with no exogenous income in periods 15–18. In the "assisted savings" (AS) treatment, subjects received 80 lab dollars in every period. Subjects earned dividends on shares and five percent interest on retained cash (after consumption and share transactions, but before dividend payments). Given income and lab cash balances from previous periods, participants could decide how much to invest, save, or consume during the trading period. Fig. 1 provides a timeline of a single period in the experiment.

The exogenous income levels for the two treatments were selected to yield approximately the same present value of income. The small difference is due to our desire to use prominent numbers like 80 and 100. Therefore, the assisted savings treatment can be thought of as resulting from a reduction in income in the first 14 periods that is used to pay $80 in the post-retirement periods 15–18. The small present value differential caused by our use of prominent income numbers is controlled for in the analysis by expressing measures as percentages of optimal levels.

Six market sessions (9 participants, 18 periods each) were run in each treatment. As each participant was automatically endowed with six shares at the beginning, there were 54 shares in total, each of which paid a dollar dividend in each period. Each of the 18 periods began with a consumption decision and the submission of limit orders to buy or sell shares. A limit sell order consisted of a number of shares offered and a minimum willingness to accept. Similarly, a buy order specified the number of shares requested and a maximum willingness to pay for each share. Subjects could submit a buy order, a sell order, neither, or both. (In all cases, the buy price must be below the sell price to prevent "self trading".) At the same time, subjects used a drop-down menu to select a consumption expenditure (lab dollars) and the associated increase in final earnings ("take home dollars"). The asset market was cleared by arraying the buy orders by bid amount from high to low,

[5] Given the assumed boundary conditions listed below (2), it is straightforward to show that having the terminal price set equal to V/r ensures that Eq. (3) holds with $t = T$, since consumption in period $T+1$ is the sum of carryover dividends and interest, plus the receipts from share redemptions: $c_{T+1} = s_T D + (1+r)b_T + s_T V$.

[6] Noussair and Matheny (2000) also use this method of paying the present value of an asset in the pre-announced final period to induce an infinite horizon. In another treatment, they use a fixed, known probability of termination to induce an infinite horizon. They conclude behavior in these two treatments is substantially the same in terms of directions of deviations of consumption from optimal levels. Sudden consumption spikes ("binges") are common in both treatments, but the rate of binge behavior is slightly higher (17%) with the random stopping rule. Their other treatments vary the size of initial capital stocks and the nature of the production technology that permits subjects to invest and transfer resources from one period to another. In our setup, this transfer technology is linear, as determined by the exogenous interest rate on cash.

and arranging the limit sell orders by offer price from low to high. The steps on the bid and ask arrays corresponded to the numbers of shares indicated in each order. These arrays determined a uniform market-clearing price at which the number of shares that traders wish to purchase is equal to the number of shares that traders wish to sell, with ties decided at random. After the market cleared, traders could view the list of accepted and rejected bids and asks, along with their own purchases or sales, dividends on final share holdings, and interest payments on cash holdings after consumption and share transactions, but prior to dividend payments. Each market period lasted for about 4 min and ended when all decisions were submitted and confirmed.

Once the market had cleared, the computer determined the clearing price and allocated shares to the participants. Furthermore, each share yielded a dividend of one lab dollar at the end of each period. Shares were redeemed for $20 after the final period. This redemption amount induces a flat fundamental value of $20, which is equal to the ratio of the dividend, $1, and the interest rate, 0.05.[7]

As noted previously, the conversion of each period's consumption into final earnings was done using the CRRA utility function $u(c) = (3/2)c^{2/3}$, which yields a geometric optimal consumption path $c_{t+1} = (1+r)^3 c_t$. This function was adjusted with additive and multiplicative constants: $u(c) = 0.04(\frac{3}{2})c^{2/3} - 0.2$, where the 20 cent negative constant was selected to clearly indicate the suboptimality of consuming small amounts. The 0.04 multiplier was selected to set an appropriate earnings level. Lab dollars that were not consumed (i.e. saved) carried over from one period into the next and received interest at the end of each period. On the basis of a pilot experiment that generated a large price bubble, we expected asset price portfolio choices to interfere with optimal saving decisions. The pilot was conducted with deterministic share dividends, which did not dampen speculative behavior, and therefore, was used in all sessions.

The experiments were conducted at the University of Virginia, with subjects recruited from a mixed-gender pool of students.[8] The experiment was run with web-based V*e*conlab software and instructions that are reproduced in the Appendix. Instructions were read out loud at the start of each session, while participants viewed the instructions pages on their computer screens. Each session began with a two-period practice market, where participants could become familiar with the software and decision environment. In the assisted savings treatment, both practice rounds had an equal income of $80, whereas in the private savings treatment, there was one round with an income of $100 and a second with no income. The purpose of the practice was to make sure that subjects understood the consumption process of converting lab dollars into cash earnings, the call market trading, interest and dividend procedures, and the final forced consumption of asset redemption values and all remaining cash. The two-period practice, however, was intentionally shortened so that it would not provide subjects the chance to live their economic lives twice. After the practice rounds were completed, a summary instructions page reviewed the payoff procedures, exogenous income receipts, and final payoff procedures. The 18 periods of asset trading and consumption followed, after which participants were forced to consume all remaining lab cash and share redemptions by converting this amount into take home earnings via the nonlinear utility transformation. All converted consumption expenditures from the practice periods and the research periods were paid in U.S. dollars at the end of the experiment. Final earnings (for all rounds, including practice rounds) ranged between $20 and $30, including a $6 show-up payment.

4. Experiment results

It is natural to expect subjects to save less in the assisted savings treatment, which automatically provides a flat income trajectory throughout the life cycle. Even though optimal private savings amounts should be lower with assisted savings, a more interesting issue is whether the behavioral response to the assisted savings is fully or only partially offsetting relative to what is optimal. If the behavioral response to the treatment differences in exogenous incomes is fully responsive, then the resulting consumption path should be essentially the same. Therefore, we will begin by deriving the pattern of optimal consumption expenditures for each treatment. Recall that the utility function used for the cash conversions determines an increasing consumption trajectory, $c_{t+1} = (1+r)^3 c_t$. This condition can be used to determine the initial-period consumption level that grows geometrically. In particular, the final consumption based on final period redemptions and remaining cash must exactly fit the optimal geometric growth pattern. These calculations are done under the assumption that participants simply hold their share endowments and collect dividends and final redemption payments, so that the resulting consumption levels can be compared with optimal levels over the whole life cycle. Individual earnings will vary as a result of differences in savings and speculative gains in the asset market, as noted below.

An optimal consumption path is associated with an optimal saving trajectory. The dashed lines in Fig. 2 show the associated optimal cash holdings (savings) over the life cycle for each treatment. Optimal savings are higher for the private savings treatment (dark dashed line) than for the assisted savings treatment (light dashed line). The thin lines show the

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[7] See Holt et al. (2017, section II) for a derivation of the fundamental value based on backward induction and an assumption of perfect foresight. The intuitive idea is that a share priced at $20 that pays a $1 dividend offers a 5 percent return that matches the return on cash. The final redemption of $20 captures the present value of the future after that point. Holt (2019, chapter 24) contains an overview of asset market experiments with flat values.

[8] Eckel and Füllbrunn (2015) find that explicit gender sorting can matter in asset markets with a declining fundamental value. For the flat fundamental value design used here, Holt et al. (2017) report that there is no significant difference in asset bubble formation between all-male and all-female markets, but mixed gender groups were used in any case.

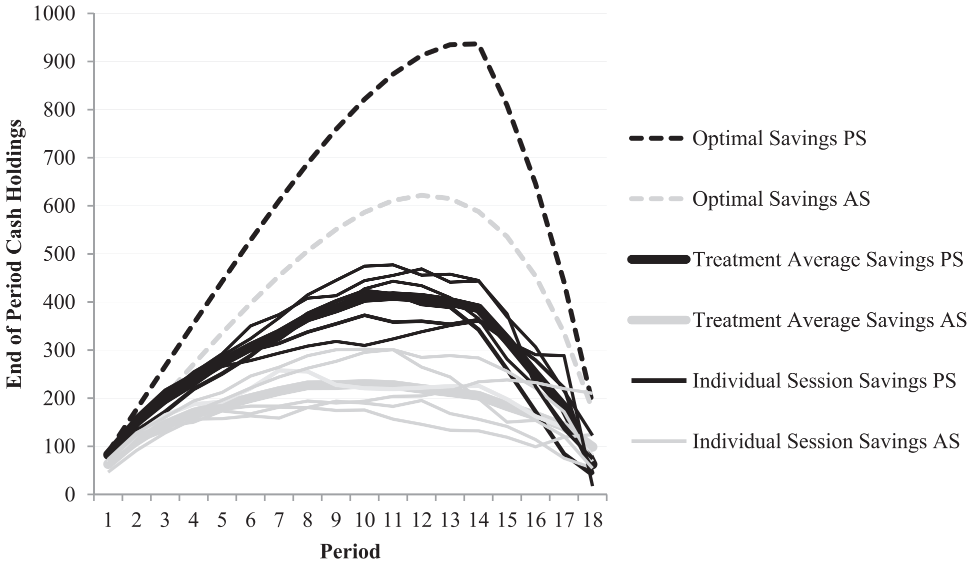

Fig. 2. Life cycle cash savings: dark lines for the private savings (PS) treatment, and light lines for the assisted savings (AS) treatment.
Note: The thin lines are for the 6 sessions in each treatment, with treatment averages shown by the thick lines. Optimal cash savings for each treatment are plotted as dashed lines.

savings levels, period by period, for the six sessions in each treatment, and the thick lines show the treatment averages across all sessions (dark lines for private savings and light lines for assisted savings).

The qualitative features of the savings paths motivate our first qualitative conclusion:

Result 1. Non-optimal savings: Savings are lower for all sessions in the assisted savings treatment, but savings levels are only about 50 percent of the optimum for both treatments.

Support: While the fifty percent of optimal levels for each treatment is only an approximate description, the treatment comparison is strongly supported by a statistical test. There is no overlap in terms of the peak savings level by session, with peaks for all six sessions being higher for the private savings treatment (dark lines). This difference is significant ($p < 0.01$) for a nonparametric permutation test using the 6 savings peaks for each treatment.

Inadequate savings result in reductions in earnings from consumption (utility) conversions. A useful overall measure of consumption optimality is the ratio of total consumption earnings over all periods to the earnings that would result from optimal consumption. The left column of Table 1 shows the consumption optimality ratios by session for each treatment. The overall consumption optimality measure is about 89 percent for the private savings treatment, which is approximately 4 percentage points lower than for assisted savings, which motivates our second result.

Result 2. Overall consumption optimality: The ratio of overall consumption to optimal consumption is significantly and economically higher in the assisted savings treatment.

Table 1
Consumption measures by session.

Treatment	Consumption optimality ratio	Average consumption in periods 1–10	Average consumption in periods 11–14	Average consumption in periods 15–18	Peak price
Assisted savings					
Macc 5 AS	0.932	74.06	102.50	127.49	42.50
Macc 11 AS	0.929	72.78	95.00	143.31	21.25
Macc 15 AS	0.925	74.99	103.33	123.38	30.00
Macc 19 AS	0.945	65.57	102.44	156.15	26.00
Macc 23 AS	0.931	65.86	123.33	137.03	43.00
Macc 27 AS	0.923	74.03	85.83	148.02	38.00
Average AS	**0.931**	**70.65**	**105.32**	**137.47**	**33.46**
Private savings					
Macc 7 PS	0.872	81.20	125.056	109.53	42.00
Macc 9 PS	0.908	76.13	144.17	102.44	36.00
Macc 13 PS	0.915	75.93	140.83	108.59	53.00
Macc 17 PS	0.886	72.57	135.00	127.18	61.50
Macc 21 PS	0.846	86.37	109.42	109.36	38.50
Macc 25 PS	0.893	75.49	127.50	124.99	70.00
Average PS	**0.887**	**78.44**	**130.89**	**111.42**	**50.17**

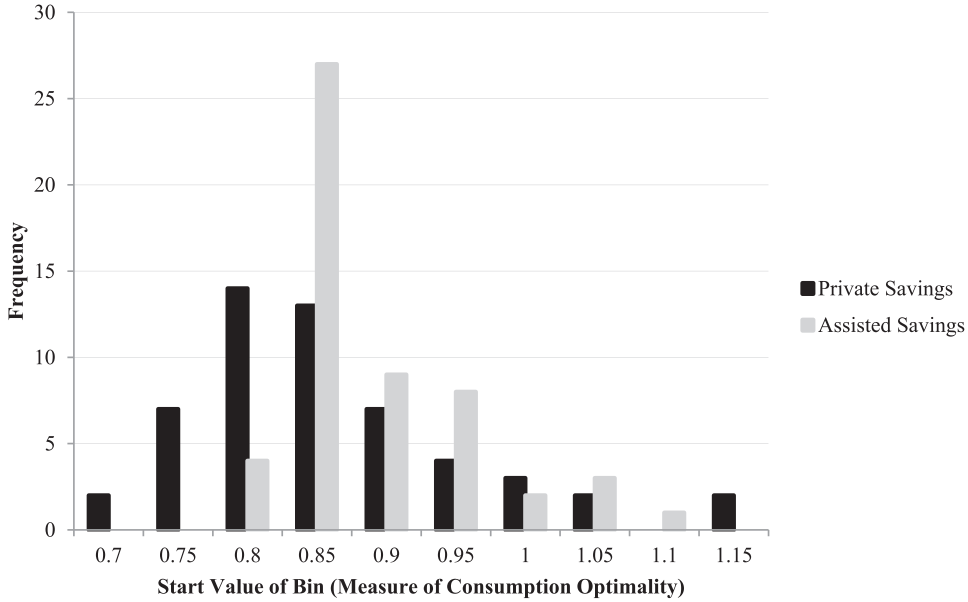

Fig. 3. Distribution of traders sorted by consumption optimality ratios: dark bars are for the private savings (PS) treatment, and light bars for the assisted savings (AS) treatment.
Note: Individual ratios are calculated as total consumption earnings divided by earnings from optimal consumption.

Support: Consumption optimality ratios in the first column of Table 1 for assisted saving are all higher than those for private saving, with no overlap. This difference is significant, $p = 0.002$ (two-tailed exact permutation test, 12 observations).

The consumption optimality measures used for this result pertain to the whole life cycle. The effects of interest compounding can cause relatively small amounts of overconsumption early in the life cycle to have large effects on overall performance. The enhanced impact of errors made early in the life cycle, however, is an important feature of actual consumption decision-making. Our focus here is on overall performance relative to optimality for a representative agent who holds initial share endowments, and not on conditional optimality of decisions made along the path as shareholdings and values evolve.

Even though savings levels in Fig. 2 are clearly too low relative to optimal levels, there is some individual heterogeneity. Fig. 3 shows the distribution of individual consumption optimality ratios, calculated as previously explained. Note that subjects who do speculate successfully in the asset market will have higher consumption, resulting in optimality ratios above 1, as long as the time pattern of consumption is well adjusted. As before, dark bars are for the private savings treatment and light bars are for the assisted savings treatment.

Result 3. Individual heterogeneity: Consumption optimality ratios are generally higher and less variable across individuals in the assisted savings treatment.

Support: As shown in Fig. 3, the modal individual in the private savings treatment achieved an overall consumption level at about 80 percent of optimal, whereas the modal ratio was about 85 percent for those in the assisted savings treatment, with about twice as many people at the mode in the latter case. There could be some interaction between individuals within a session, due to asset market trading and the resulting expectations. Therefore, we use a Kruskal–Wallis test to determine whether the consumption optimality ratios differed by session from a statistical perspective. Using this test, we are unable to reject the null hypothesis that all the observations for a given treatment are drawn from the same underlying population of individual consumption optimality ratios (with p values: $p_{AS} = 0.97$, $p_{PS} = 0.89$). This test provided us some justification for treating individual optimality ratios within each treatment as being independent observations. We report a two-tailed permutation test to check for differences between treatments. In this case, we were able to reject the null hypothesis that treatments are the same ($p = 0.048$). In other words, randomly permuting the treatment labels for individual consumption optimality ratios yields higher absolute treatment differences in less than 5 percent of the permutations.[9]

The consumption trajectories provide a clearer picture of how treatment differences emerge. Fig. 4 shows consumption expenditures by session for each treatment, coded by light/dark shading as before, with the thick lines showing treatment averages across sessions. Optimal consumption grows smoothly over time, as shown by the smooth dashed lines generated by the optimal compounded consumption growth derived in the previous section: $c_{t+1} = (1.05)^3 c_t$.

[9] Instead of considering the billions of possible permutations, this test was done by measuring tail areas based on 100,000 simulations. For all other tests based on independent session-level measures, we use exact permutation tests instead of the simulations needed for large numbers of individual observations.

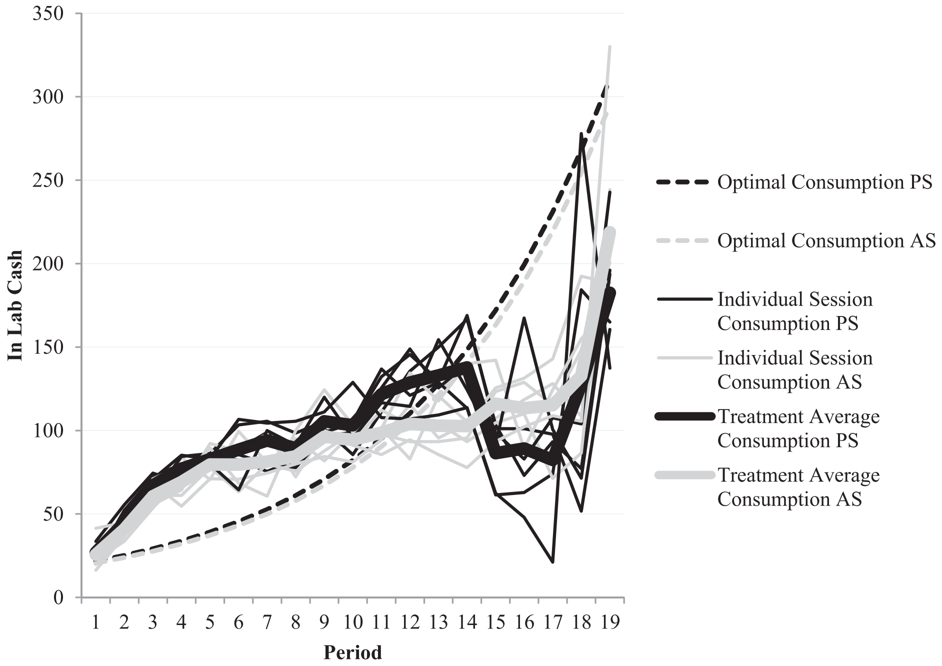

Fig. 4. Consumption profiles for individual sessions for private savings (dark lines) and assisted savings (light lines), compared with optimal consumption profiles (dashed lines).

Result 4. Temporal comparisons: In early periods, subjects in both treatments overconsume relative to optimal levels. Conversely, all sessions exhibit under-consumption relative to optimal levels in the retirement periods (15–18). The initial over-consumption in periods 1–14 is higher in the private savings treatment, and the under-consumption in the retirement periods 15–18 is also more pronounced in the private savings treatment.

Support: Average consumption levels in Fig. 4 are initially lower for the assisted savings treatment (light thick line) than for the private savings treatment (dark thick line), and this pattern is reversed in the retirement periods 15–18. Statistical support is provided by two-tailed exact permutation tests (based on all 924 permutations of the treatment labels for the 12 sessions). The session-level average consumption amounts used for this test are provided in the middle columns of Table 1, for initial periods 1–10, pre-retirement periods 11–14, and retirement periods 15–18. The p values (higher consumption with private savings) are $p = 0.024$ for periods 1–10 and $p = 0.004$ for periods 11–14 (two-tailed tests, 12 observations). For the retirement periods 15–18 (higher consumption with assisted savings), the significance is comparable, with $p = 0.008$ (two-tailed test, 12 observations).

Asset price sequences are somewhat variable from one group of traders to another, due to differences in propensities to speculate. One major result of the asset market bubble literature is that excess cash is an important driver of bubble formation (Caginalp et al., 2001). In our setup, private savings are available to traders for speculative purposes, and this suggests that bubbles would be higher in the private savings treatment. This difference is apparent in Fig. 5.

Result 5. Price bubble formation and savings: Price bubbles above fundamental value are pervasive in both treatments, but bubbles are significantly higher in the private savings treatment than in the assisted savings treatment, which results in lower cash holdings.

Support: We use the peak price as a measure of bubble intensity in this flat-fundamental value context. Average peak prices in the right column of Table 1 are about 50 percent higher in the private savings treatment, although there is some overlap across groups (sessions). This difference is significant at the 5 percent level (two-tailed exact permutation test, 12 observations, $p = 0.039$).

It is also notable that price bubbles occurred despite the tendency for consumption to drain excess cash from the system. Crockett et al. (2019), in contrast, do not observe overpricing of risky assets in their treatment with concave utility that induces consumption smoothing. Asparouhova et al. (2016) also do not observe asset price bubbles, which they attribute to “incessant incentives to trade” induced by heterogeneous endowments, state-dependent incomes, etc. Halim et al. (2016) do find asset prices to be consistently higher than their fundamental value and quite variable. More interestingly, when people had less or no incentive to smooth consumption (which would be equivalent to a linear utility function in our experiment), asset prices were more volatile and over-pricing was generally higher. One way to understand these results in the context of the “excess cash hypothesis” is that bubbles tend to be larger with more free cash in the system. Fenig et al. (2017) report an experiment involving a rich macroeconomic setting with labor and asset markets. One of the macroeconomic policies

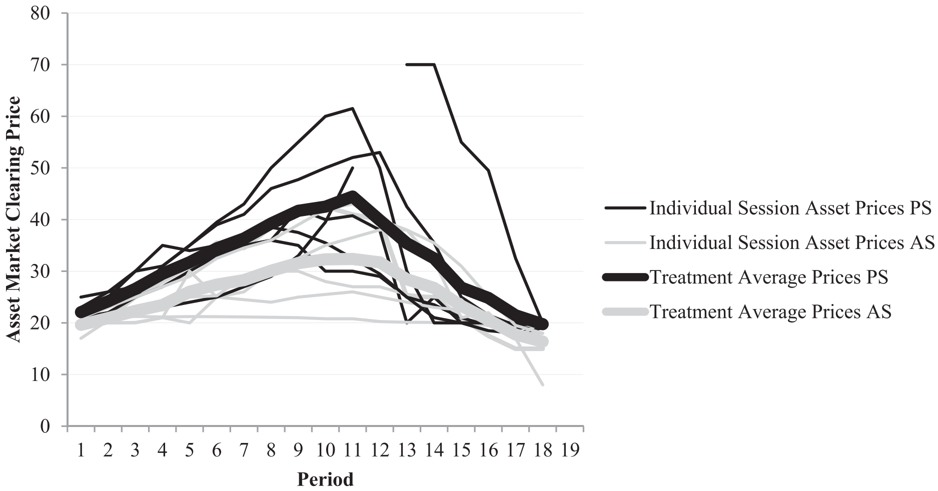

Fig. 5. Asset price sequences for individual sessions for private savings (dark lines) and assisted savings (light lines), compared with the $20 fundamental value for both treatments.
Note: Average asset prices across all sessions in each treatment are plotted as thick lines. The gaps in individual session price sequences were caused by a period with no trades.

considered (the prospect of a binding leverage constraint) tends to increase labor supply, resulting in the accumulation of cash balances and associated price bubbles.

5. Robustness checks: comparisons without asset market trading

A typical individual's life experiences generate a range of distractions that interfere with prudent savings behavior. Speculative opportunities in the asset market provided this type of distraction, but these opportunities had other effects like creating wealth inequalities in later rounds. In this section, we report a parallel experiment in which asset market trading was shut down. In order to minimize changes in instructions and overall complexity, individuals still received 6 shares paying a known $1 dividend each period with the same $20 redemption value. Then the 5 percent interest and the use of the same exogenous income streams for the assisted and private savings treatments result in the same optimal consumption patterns as before. The removal of share trading tends to simplify the decision environment, although the inability to sell share endowments adds an element of forced saving. Without trading opportunities, this becomes an individual decision task, with each subject providing an independent observation, which is summarized by a consumption optimality measure. The optimal consumption earnings totals for the previous private and assisted savings treatments can be used to characterize each subject's performance with a consumption optimality ratio. Given the larger numbers of independent observations (nine observations per market group instead of one), we only ran three groups of 9 subjects in each treatment, private and assisted savings.

After that, we ran another set of paired treatments with no trade and a sharply reduced interest rate (1 percent), again with three nine-person groups per treatment.[10] The instructions were basically the same (without references to market bids, asks, and trades) and the procedures were also the same (except as noted), with a two-period practice done prior to the series of 18 periods, followed by a nineteenth period with required conversions of remaining cash and share redemptions ($20 per share as before).

First consider the effects of removing asset market trade, keeping the interest rate high at 5 percent. The new overall pattern of consumption relative to optimality predictions shown in Fig. 6 exhibits overconsumption in early periods and underconsumption during retirement, which is qualitatively similar to that in Fig. 4 with asset trading.

Fig. 7 shows the average and optimal consumption profiles for assisted and private savings under a 1 percent interest rate and no asset trading. It is important to note that due to the smaller effect of compounding interest, the optimal consumption paths are much flatter and essentially indistinguishable. The observed average consumption for both assisted and private savings treatments track the optimal paths more closely than under a higher interest rate scenario, albeit with some substantial divergences in the retirement period.

Two additional observations are worth mentioning. First, the average subject in the AS treatment does not overconsume in the earlier periods in contrast to behavior in all treatments with a high interest rate. Second, the average savings in

[10] There was one subject who did not show up in the final session with 1 percent interest, and we continued with only 8 subjects since the task involves no interaction.

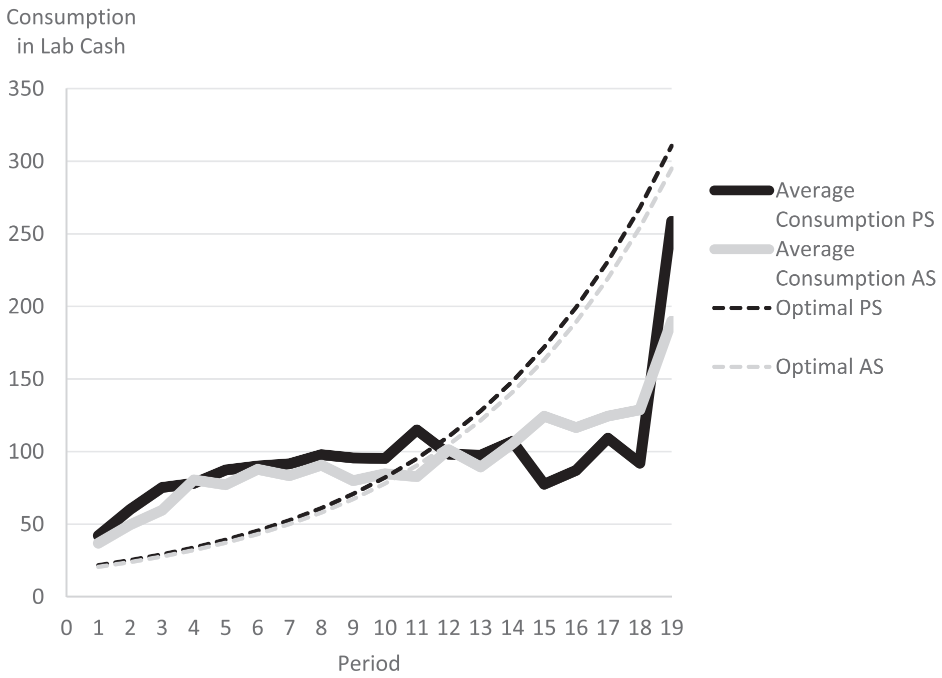

Fig. 6. Consumption profiles with no asset trading and 5 percent interest, for private savings (dark lines) and assisted savings (light lines), compared with optimal consumption profiles (dashed lines).

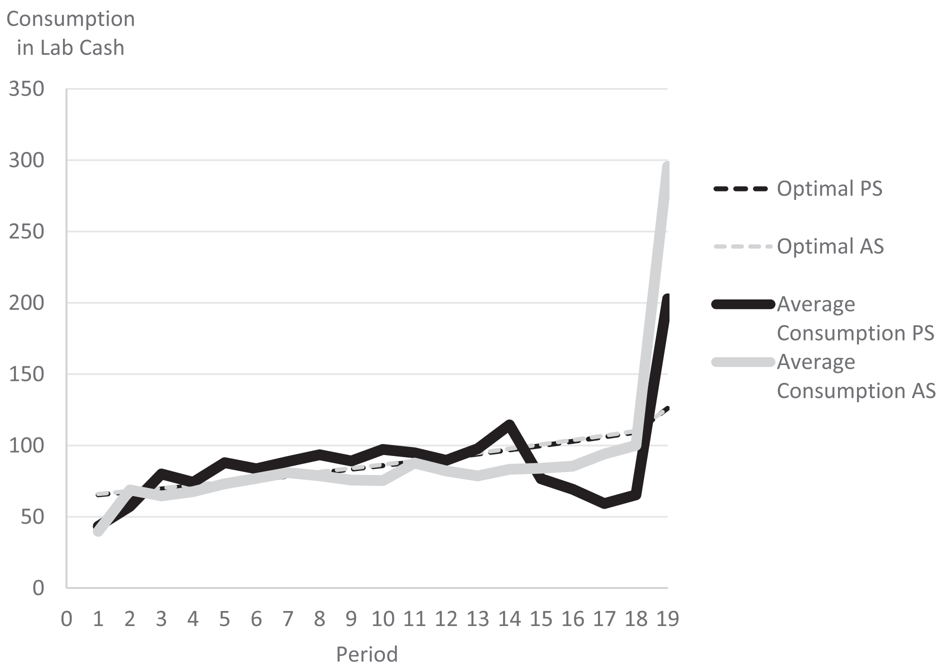

Fig. 7. Consumption profiles with no asset trading and 1 percent interest, for private savings (dark lines) and assisted savings (light lines), compared with optimal consumption (dashed lines).

Fig. 7 tend to be too high in the final period for both low-interest treatments of AS and PS, despite not consuming enough in the preceding retirement periods, which results in a spike at the end.

Taken together, these patterns suggest that the assisted savings program continues to improve consumption behavior even without asset market trading (Fig. 6), but that this relative improvement is diminished in the absence of high levels of interest compounding (Fig. 7). Table 2 compares the previous consumption optimality results with and without asset market trading for each treatment (PS or AS). As shown in the first row for an asset market with a 5 percent interest, the

Table 2
Average consumption optimality measures by treatment.

	Data structure	Private savings consumption optimality	Assisted savings consumption optimality	Permutation test assisted vs. private savings
Asset trade 5% interest	6 market measures per treatment	0.887	0.931	$p = 0.002$[***]
No asset trade 5% interest	27 subject measures per treatment	0.902	0.941	$p = 0.0004$[***,a]
No asset trade 1% interest	26-7 subject measures per treatment	0.944	0.954	$p = 0.56$[a]

[a] Permutations tests with 54 observations are based on 100,000 random simulated permutations.
[***] Significant at the 0.01 level, two-tailed permutation test.

average consumption optimality measure is about 4 percentage points higher in the assisted savings treatment; a difference that is highly significant, as indicated by the low permutation test *p* value on the right side, which was previously used to support Result 2.[11] The second row of Table 2 shows comparable results with no asset trading, again with a very low *p* value based on random permutations of the 27 optimality measures for each treatment. The performance improvement in the assisted savings treatment in this row is again about 4 percentage points. This result shows that the performance differences reported in the previous section are not merely artifacts of the asset market trading, as summarized in Result 6.

Result 6. Asset trading implications: Subjects performed only slightly better without the confounding effects imposed by the asset market. In particular, the assisted savings treatment with no asset market resulted in significantly higher consumption optimality measures than the private savings treatment with no asset market, a difference that is similar in magnitude to what was observed with asset trading.

Support: Disabling the asset market simplified the decision problem only slightly and increased consumption optimality ratios by approximately 1 percentage point in both the assisted savings and the private savings treatments (as shown by the differences between optimality ratios in the top two rows of Table 2). In the AS treatment, there is generally less variability across subjects' performances. The increase of average consumption optimality (from 0.931 to 0.941) was marginally significant, with a *p* value of 0.06 using a two-tailed permutation test. Unsurprisingly, the consumption optimality ratios for PS with no asset market were not significantly higher than the corresponding optimality ratios for PS with an asset market, since the observed optimality increase did not outweigh the larger heterogeneity in subjects' performances without the assisted savings. On the other hand, the difference in optimality ratios between the AS and PS treatments without trade (middle row of Table 2) was of similar magnitude, about 4 percentage points, as that observed previously with asset trading.

Next consider the effects of reducing the interest rate from 5 to 1 percent, in the absence of asset market trading. As a result, subjects' consumption optimality measures increase for both assisted and private savings treatments to an average of around 95 percent. Note that the averages shown in the bottom row of Table 2 are approximately the same for the assisted and private savings treatments, which motivates our final result:

Result 7. Reduced interest rates: Under a sharply reduced interest rate, subjects' observed optimality measures were higher in both assisted and private savings treatments compared to the previous scenarios. However, the assisted savings treatment no longer provides a significant benefit relative to the matched private savings treatment.

Support: The same permutation test that was used in the top part of Table 2 shows no significant difference between assisted and private savings treatments for the data in the bottom (for 1 percent interest and no trade), again with 27 subjects per treatment. Note that the sharp interest rate reduction raised optimality in the PS treatment (from 0.902 in the middle row to 0.944 in the bottom row), but not in the AS treatment. This optimality increase for an interest rate reduction with private savings is also significant ($p = 0.0034$, 2-tailed permutation test, 54 observations). Furthermore, the AS treatment did not induce a higher consumption optimality ratio, with a *p*-value of only 0.56 between the PS and AS treatments. As subjects were no longer able to improve their high optimality measures much with assisted savings, this treatment provided little extra benefit.

The follow-up interest-rate treatments (without asset trading) are useful for understanding the nature of subjects' suboptimal behavior. In particular, inadequate savings can be partially explained by a failure to appreciate and leverage the effects of interest compounding. With the high interest (5%), consumption should be increasing in later periods, but the dark-line consumption average in Fig. 6 for private savings is fairly flat after the midpoint (period 9). Indeed, average consumption in the critical pre-retirement phase (periods 11–14) is no higher in the 5% interest treatment with private savings (dark line in Fig. 6) than it is with 1% interest for the same periods in Fig. 7.

The failure to save enough to increase later consumption is made even more apparent by considering cash savings data. With private savings and 5% interest, the optimal savings accumulation would be 759 after period 9, more than double the average individual savings level of 324 at that point. In contrast, the average observed savings of 272 in period 9 with 1% interest is much closer to the optimal level of 303. This close correspondence between optimal and observed savings for all periods in the low-interest treatment is indicated by a comparison of the gray dashed and solid lines in Fig. 8. In contrast,

[11] Even though there are only 12 independent observations, this low *p* value is due to the low proportion of the 12-take-6 random permutations that would yield the most extreme result in either direction, with all optimality measures for one treatment higher than for the other.

Fig. 8. Interest rate effects in the private savings treatment with no income after period 14: optimal savings levels (dashed lines) and observed average savings (solid lines).
Note: With 5% interest and private savings (PS), observed savings levels are only about half of optimal levels (dark lines), but average savings track optimal levels closely (gray lines) in the analogous 1% interest treatment. Compound interest bias is indicated by the closeness of the actual savings trajectory (dark line) with high 5% interest to the optimal savings for the minimal interest treatment (dashed gray line).

the solid dark line savings pattern for the 5% treatment is not far from the optimal path for the other, low-interest treatment. The subjects are not responsive to the incentive to save more in the presence of high interest that gets compounded.

6. Discussion

This research contributes to the literature on lifetime savings and consumption decisions. Overall, we find that subjects consume suboptimally as they "get older" in experimental time periods. This finding is particularly pronounced in the private savings treatment. While those in the assisted savings treatment fared relatively better in terms of smoothing their consumption, they still have a long way to "save" before they can achieve lifetime optimal consumption.[12]

More specifically, we find that people save less than fifty percent of the corresponding optimal level in both savings treatments of our main experiment, and that the low savings cause a distorted consumption pattern. The average consumption optimality ratio is not close to 1 in either treatment, but this ratio is significantly higher with assisted savings. Suboptimal lifetime consumption is characterized by overconsumption early and underconsumption after retirement. Both aberrations are stronger in the private savings treatment. The literature on "excess cash" effects in asset market experiments suggests that the higher price bubbles in the private savings treatment are a consequence of the frontloaded incomes and higher available cash in early rounds.

Since both treatment groups obtained the same level of information regarding income streams and lifespan, in theory, they both should have been able to plan for consumption and savings balances equally well. The fact that we observe diverging consumption patterns implies that the timing of the disbursement of income payments over the course of a "lifetime" matters. The relatively smoother consumption paths in the AS treatment provide support for the use of government-assisted retirement savings programs. Nevertheless, the observation that consumption and savings are below optimality in both treatments merits further analysis.

The follow-up experiment with interest rate variation provides insight into the sources of suboptimal behavior. These results indicate that most subjects fail to appreciate the effects of exponential savings growth. Observed consumption behavior improved when subjects did not have to face the effect of substantial interest compounding. Moreover, when interest rates are significantly reduced, there is little space for further improvement, and we find that the assisted savings treatment provides no increase in consumption optimality over that for private savings. Assisted savings are therefore more critical in the presence of relatively "high" interest. There is a weaker incentive to save with low interest rates, since the interest compounding effect is not particularly strong. As subjects display an aversion to saving in general, they will naturally behave more optimally when smaller savings levels are sufficient.

Other important motivations for saving are precautionary and anticipatory. Precautionary saving involves building up a sufficient reserve for covering random expenditures due to adverse events like illness or accidents. Similarly, anticipatory savings refer to achieving a high enough savings level to pay for certain expenditures such as housing, college education, or retirement. Bohr (2017) evaluates the effects of private and assisted savings treatments in a model that is richer in

[12] It is important to recognize that differences in savings rates between countries can be due to a variety of factors such as culture, local monetary policy, and experiences with financial and economic crises. For instance the "Gallopierende Inflation" of 1923 in Germany is still referenced in German economics textbooks. By doing an experiment within the U.S., we held culture constant and focused on the differences in savings behavior induced by the treatments.

the sense that it includes the unanticipated costly events, but simpler in terms of a setting without discounting and risky assets. Nevertheless, the general conclusion is that assisted savings programs have the potential to smooth consumption and mitigate the effects of behavioral biases.

One task for further research is to analyze alternative mechanisms with which the voluntary savings contributions can be increased. In the field, some studies have already highlighted the importance of information and financial education in increasing the voluntary savings rate (Clark et al., 2006; Duflo and Saez, 2003). The next step would be to test the micro-level impact of information and incentive treatments on savings and consumption decisions in lab experiments.[13]

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.euroecorev.2019.05.020.

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[13] Other promising savings mechanisms include Prize-Linked Savings Accounts (PLSA), which offer the financial security of regular savings accounts. However, rather than individuals earning a steady interest, PLSA participants are entered into a lottery with the chance to win a large monetary prize. PLSAs were initially developed in South Africa to incentivize low-income, gambling-prone households to open savings accounts, and are now becoming popular across the world as well as in many U.S. states. Cole et al. (2017) found that PLSAs in South Africa encouraged participation by individuals with no previous deposit accounts. In addition, they enticed the average participant to save more. The savings inducement effects of lottery-based savings opportunities are confirmed in a recent laboratory experiment (Feliz-Ozbay et al., 2015).