

Exponential Growth Bias and Household Finance^{*}

Victor Stango
Graduate School of Management
University of California, Davis

Jonathan Zinman
Department of Economics
Dartmouth College

June 2008

Abstract

We document two widespread biases in how consumers perceive the costs and benefits of borrowing and saving, and explore the implications of these biases for household finance. *Payment/interest bias* is the systematic tendency to underestimate a loan interest rate given other loan terms. *Future value bias* is the systematic tendency to underestimate a future value given a present value, time horizon and periodic rate of return. We show that these biases may have a single cognitive source: *exponential growth bias*, the pervasive tendency to linearize exponential functions. Most importantly we show that these biases seem to affect household decisions and outcomes. Conditional on a rich set of household characteristics, a household-level metric of payment-interest bias is strongly correlated with borrowing, savings, portfolio choice, wealth and delegation. There is only weak evidence that our measure of bias merely proxies for broader financial sophistication. In all the results suggest that exponential growth bias represents a new class of behavioral biases that should be modeled in theoretical and empirical work on household finance.

JEL codes: D1, D9, G11

Keywords: exponential growth bias, household finance, intertemporal choice, psychology and economics, behavioral economics, behavioral finance, present-bias, financial sophistication, financial literacy

* Contacts: vstango@ucdavis.edu, jzinman@dartmouth.edu. Thanks to Jonathan Bauchet for research assistance and to Bob Avery and Art Kennickell for discussions on the 1983 Survey of Consumer Finances. Thanks to Andy Bernard, Dan Benjamin, James Choi, Xavier Gabaix, Al Gustman, David Laibson, Anna Lusardi, Ted O'Donoghue, Jesse Shapiro, Jon Skinner, Doug Staiger, and seminar/conference participants at the Yale SOM Behavioral Science Conference, Kellogg, Cornell, UC Davis, Georgetown, IZA, SITE, the AEA Annual Meetings, the Federal Reserve Banks of Boston, Chicago, and Philadelphia, the Federal Reserve Board, the Federal Trade Commission, the University of Michigan Retirement Research Center, the Dartmouth Economics Department and the Dartmouth Social Psychology Research Interest Group for comments. Special thanks to Chris Snyder for help with the math of exponential growth bias. A previous version of this paper circulated with the title "Fuzzy Math and Household Finance: Theory and Evidence".

I. Introduction

What drives household financial decisions? The canonical economic model assumes that consumers choose to consume, borrow, or save based on their preferences, expectations, and the costs and benefits of borrowing and saving. A growing body of work applies specific insights from psychology to enrich specifications of three of the model's key pieces: preferences, expectations, and problem-solving conditional on parameter values.¹

We bring psychological evidence to bear on a fourth specification issue: how consumers perceive the costs and benefits of borrowing and saving. We tie together existing and new evidence on these perceptions to show that most consumers err systematically when given information commonly available in the market. On the saving side, consumers display *future value bias*: a systematic tendency to underestimate a future value given a present value, time horizon and rate of return.² On the borrowing side, we present new evidence that consumers display *payment/interest bias*: a systematic tendency to underestimate a loan interest rate given a principal, monthly payment and maturity. The biases vary asymmetrically with maturity: future value bias increases with the time horizon, and payment/interest bias declines with maturity.

The striking thing about these perceptions of costs and benefits is not that consumers make *mistakes*, but that the mistakes are *biased* in particular ways. The “wisdom of crowds” fails here, and fails to a greater or lesser degree depending on side of the balance sheet and maturity. What explains this particular pattern? And is the pattern indicative of biases that affect actual decisions?

We show that future value bias and payment/interest bias are potentially linked by a single cognitive microfoundation: *exponential growth bias*, the tendency to linearize functions containing exponential terms when assessing them intuitively. A literature in cognitive psychology documents that individuals display exponential growth bias in a variety of contexts, and that the degree of exponential growth bias varies substantially in the cross-section. But economics has largely ignored the potential implications of exponential growth bias for household finance.³

The intuition for how exponential growth bias drives future value bias is clear: consumers underestimate how quickly a given yield compounds, so they underestimate the expected future

¹ We borrow this three-pronged taxonomy from DellaVigna's (2007) review of field evidence on psychology and economics. For a review focused on behavioral finance see Barberis and Thaler (2003).

² Future value bias is our term for the tendency documented most directly in Eisenstein and Hoch (2005).

³ The cognitive psychology literature began with Wagenaar and Sagaria (1975); we provide a brief review in Web Appendix A. Economic applications of exponential growth bias to-date have been limited to perceptions about savings (Eisenstein and Hoch 2005) and inflation (Keren 1983; Jones 1984; Kemp 1984). Exponential growth bias does not appear in any of the many reviews of psychological evidence for economists; see., e.g., Rabin (1998), Glovich, Griffin, and Kahneman (2002), Kahneman (2003).

value for any given future date. Future value bias becomes more pronounced as the periodic return rises and the compounding horizon lengthens. On the borrowing side, exponential growth bias is mathematically equivalent to failing to account for the declining principal balance on an installment loan. So consumers *overestimate* how long they actually get to borrow the principal, thereby underestimating the true cost of borrowing. Payment/interest bias is more severe on short-term loans because principal balances on those loans decline faster than on long-term loans.⁴

We then examine the critical question for household finance: does exponential growth bias affect household balance sheets in the real world? We are not aware of any prior work on this question. To answer it we construct a household-level measure of payment/interest bias, and correlate it with a wide range of household financial outcomes. Bias matters: payment/interest bias is strongly correlated with more borrowing, less saving, portfolios tilted toward short-term installment debt and short-term assets, and lower net worth.⁵ All of these results are conditional on controls for demographic and life-cycle factors, available resources, preferences, expectations and other decision inputs.⁶ While our data lack a direct measure of future value bias, the pattern of results suggests that payment/interest bias captures future value bias as well; in particular, payment/interest bias is correlated with asset allocation conditional on the level of assets.

The findings motivate four follow-on questions. First, why doesn't consumer adaptation (learning, calculators, heuristics, etc.) render bias irrelevant? In fact we find that many consumers do effectively debias themselves by relying on outside financial advice. More biased households get more outside advice, all else equal, suggesting that many consumers are aware of their bias and/or its effects. And more-biased households who get outside advice are just as wealthy as the least-biased households. Yet our results also suggest that many biased households do not delegate, learn rapidly enough, or otherwise undo the effects of bias. Psychology again offers an

⁴ We treat the link between exponential growth bias and borrowing cost perceptions formally in Web Appendix B, but for intuition the limiting case in the other direction is instructive. The formula for the interest rate on an infinite-maturity (interest-only) loan is $i=p/L$, the periodic payment divided by the principal; it does not involve any exponentiation and the principal balance never declines, so exponential growth bias (or failure to account for declining principal balances) is not an issue.

⁵ Methodologically speaking, empirical work testing relationships between an individual-level measure of a potentially biased decision input and household/consumer financial choices is rare. Ashraf, Karlan, and Yin (2006) and Meier and Sprenger (2007) use survey questions to construct measures of time-inconsistent preferences and then examine relationships between preferences and saving or borrowing decisions. Puri and Robinson (2007) examine relationships between a measure of optimism based on life expectancy and financial decisions in the 1995-2001 Surveys of Consumer Finances. Graham, Harvey, and Puri (2007) summarize and extend the corporate finance literature on links between managerial attitudes (e.g., preferences and beliefs) and firm behavior.

⁶ Our Web Appendix C details the full set of controls. We use the 1983 Survey of Consumer Finances because no more recent dataset has data on biased interest rate perceptions. In the Conclusion we note that the expansion and increased sophistication of retail financial markets may make biased perceptions even more relevant today (despite the growth of low-cost decision aids).

explanation: cognitive biases tend to persist and decision-making heuristics to fail when decisions are abstract and made infrequently (Stanovich 2003). Many borrowing, saving, and portfolio decisions in household finance seem to fit that description.

A second question is why supply-side factors or regulation fail to eliminate the effects of bias. We do find that credit constraints play a mitigating role, by preventing some biased households from borrowing as much as they would like. Truth-in-Lending law could make payment/interest bias irrelevant by forcing lenders to disclose an annual percentage rate (APR), but the APR disclosure mandated by Truth-in-Lending is imperfectly enforced. Many lenders use “monthly payment” marketing that shrouds or misrepresents interest rates, itself *prima facie* evidence that bias matters in the market given that violating Truth in Lending is costly.⁷ Our companion paper examines the issue in further detail, and shows that consumers with greater payment/interest bias pay higher loan interest rates (Stango and Zinman 2007).⁸ On the saving side, firms selling saving and investment products have incentives to debias consumers, but regulation may hinder them from highlighting returns over long horizons, where future value bias is most severe.⁹

A third question is whether our results reflect the specific effects of exponential growth bias, or whether bias is a measure of low financial sophistication defined more broadly.¹⁰ On the asset side of the balance sheet, we conduct additional tests by estimating conditional correlations between our bias and standard indicators of sophistication, focusing on outcomes that would not necessarily be driven by exponential growth bias in its narrow form. The most-biased households are less likely to hold bonds, but the correlation is economically small. There is also some evidence of a relationship between bias and poor diversification. On two other indicators – holdings of own-company stock and frequent stock trading – we find no correlations with bias. On the liability side of the balance sheet, a standard hypothesis is that sophistication reduces the

⁷ See Gabaix and Laibson (2006) for a model of a shrouding equilibrium.

⁸ More specifically, we find that biased consumers pay higher interest rates on short-term installment loans, but only when borrowing from lenders that facing relatively weak Truth-in-Lending enforcement. Imperfectly enforced Truth-in-Lending may also have the perverse consequence of creating folk wisdom that using interest rates is the “right” way to make decisions and thereby nudging some biased consumers away from an effective decision rule: “Never try to infer an interest rate. Rather, make borrowing decisions based on other loan terms.”

⁹ E.g., SEC rule 230.482 requires mutual funds that advertise performance data to present 1-, 5-, and 10-year returns with equal prominence. A mutual fund that wishes to present returns earned over a longer horizon can do so, but only in addition to the 1-, 5-, and 10-year horizons, and with equal prominence. Our findings may also explain why mutual funds would highlight arithmetic rather than geometric mean fund returns. See Welch (2000) for a discussion of the difference.

¹⁰ Several papers have found positive correlations between broader measures of financial sophistication (or planning, or cognitive ability) and stock market participation or wealth, e.g.: Ameriks, Caplin, and Leahy (2003); Lusardi and Mitchell, (2007); Benjamin, Brown, and Shapiro (2006); Christelis, Jappelli, and Padula (2006); van Rooij, Lusardi, and Alessie (2007).

participation cost of borrowing. Hence one would expect our more biased households to hold less debt if unmeasured sophistication were driving our results. We find little support for this hypothesis; short-term borrowing increases with bias, and long-term borrowing is uncorrelated. Overall then there seems to be a weak relationship between bias and lack of financial sophistication more broadly. Nevertheless the results do not rule out a link between bias and financial sophistication, and we hope that they will provoke further inquiry. Perhaps, for example, being aware of one's bias is a component of financial literacy.

Fourth and finally, it is possible that our measure of bias is correlated with unobserved elements of preferences or expectations. Our controls do include measures of time preference, risk aversion, and income expectations, making it unlikely that they are omitted variables driving the results. However, we lack measures of "behavioral" biases such as time-inconsistency, loss-aversion, or optimism. So it may be the case that individuals with exponential growth bias have biases in other dimensions as well, and that those other biases drive our observed relationships between payment/interest bias and financial decisions. This is a promising line of inquiry for future theoretical and empirical work. One intriguing possibility is that exponential growth bias is a tractable way to measure a portfolio of behavioral biases.

In all, the findings offer a new class of psychological biases that might affect household finance. Previous work has incorporated psychology-based specifications of preferences, expectations, and problem-solving.¹¹ But most work in household finance continues to assume that consumers correctly perceive the decline (increase) in future consumption that results from borrowing (saving) today. Our findings suggest that exponential growth bias leads consumers to get those assessments wrong, and to err systematically in particular directions that tilt portfolios toward short-term debt and away from long-term saving, increase borrowing and reduce saving, and depress overall wealth accumulation.

The paper proceeds as follows. Section II presents evidence showing that consumers display both future value bias and payment/interest bias. Section III shows that exponential growth bias can explain both biases, and also discusses some other explanations for the pattern of biases. Section IV describes our approach to estimating the link between payment/interest bias and household financial outcomes, and also shows summary data on our outcomes and control

¹¹ For heuristic alternatives to dynamic optimization see, e.g., Lettau and Uhlig (1999), Hurst (2006), and Benartzi and Thaler (2007). There is also a related literature on financial planning; see e.g., Ameriks, Caplin, and Leahy (2003) and Lusardi (2003). For alternative formulations of beliefs see, e.g., Brunnermeier and Parker (2005) and Puri and Robinson (2007). For alternative formulations of preferences see, e.g., Angeletos, Laibson, Repetto, Tobacman, and Weinberg (2001), Barberis, Huang, and Santos (2001), and Gul and Pesendorfer (2004).

variables. Section V presents our results. Section VI discusses complementary/alternative interpretations of the results. Section VII concludes.

II. Payment/Interest Bias and Future Value Bias: Evidence

In this section we discuss previous work showing empirical evidence of payment/interest bias and future value bias, present some new empirical evidence of the former, and summarize the stylized facts that one can draw from all of the work to-date.

A. Prior Work

Eisenstein and Hoch (2005) present lab data showing that most consumers display future value bias. Their study asks internet survey participants to estimate a future value given a present value, time horizon, and interest rate. Eisenstein and Hoch show that future value bias is prevalent (over 90% of respondents err on the low side), large on average, and increasing in the time horizon.¹² Respondents display a strong tendency to anchor on a linear forecast of the future value, and to ignore the returns provided by compounding.

On the borrowing side, several previous studies contain empirical evidence that consumers make mistakes when assessing interest rates.¹³ Most studies establish this by asking respondents to estimate the interest rate implied by a given loan principal, maturity, and repayment stream. This work includes Juster and Shay (1964), National Commission on Consumer Finance (1972), Day and Brandt (1974), Parker and Shay (1974) and Kinsey and McAlister (1981). More recently, Bernheim (1995; 1998) and Moore (2003) find evidence consistent with limited understanding of loan terms, including interest rates.

The focus of prior work on the borrowing side is noteworthy; it primarily measures whether consumers make *mistakes* in assessing interest rates, rather than whether mistakes are *biased* in particular directions. The empirical implications of (presumably mean-zero) mistakes are different from the implications of bias, a point we elaborate on below. But despite the focus of previous work on measuring mistakes, it is often easy to infer from summary data provided in the

¹² Lusardi and Mitchell (2007) show that responses to a question on savings yields in the Health and Retirement Study (HRS) are consistent with the underestimation of compound yields. We note however that the HRS question does not necessarily capture a *bias* per se: its multiple choice format provides respondents with options that underestimate the yield implied by the question, but *not* with options that *overestimate* the yield.

¹³ Studying how consumers infer rates from other loan terms was motivated by lender marketing practices that emphasized monthly payments and obscured or omitted interest rates (National Commission on Consumer Finance 1972). Policymakers view accurate and unbiased perceptions of interest rates as critical because rates potentially provide a standard unit of comparison for loans with different maturities, and for loans to savings instruments with returns stated as interest rates.

papers that consumers display payment/interest bias. Some papers do make more direct statements about bias; e.g., Parker and Shay (1974) note that consumers display “a strong tendency to underestimate annual percentage rates of charge by about one-half or more...”

B. New Evidence: Payment/Interest Bias on Hypothetical Loans

We build on this prior work in several ways. We start by presenting nationally representative empirical evidence on payment/interest bias from two previously untapped sources: the 1983 and 1977 Surveys of Consumer Finances. We use the 1983 SCF because it has the most recent (and, as far as we know, the only) nationally representative data on both payment/interest bias and household financial outcomes. We use the 1977 SCF because it contains richer data on payment/interest bias than the 1983 survey; the downside of the 1977 SCF is that it lacks comprehensive data on the household balance sheet. More recent SCFs lack any questions that elicit payment/interest bias and hence are not usable for our purposes.

We measure payment/interest bias using two hypothetical questions that appear in both the 1977 and 1983 SCFs.¹⁴ The first question is:

“Suppose you were buying a room of furniture for a list price of \$1,000 and you were to repay the amount to the dealer in 12 monthly installments. How much do you think it would cost in total, for the furniture after one year -- including all finance and carrying charges?”

The response to this first question is a lump sum *repayment total* (e.g., \$1200). Given the predefined maturity and principal amount, the repayment total yields i^* , the *actual APR*¹⁵ implied by the respondent’s self-supplied repayment total.¹⁶ Figure 1a shows the distribution of the actual APR in the 1983 SCF across all households. The mean is 57 percent, which corresponds to a stream of payments over the year totaling roughly \$1350. The modal actual APR is 35% (\$1200),

¹⁴ The survey respondent is whomever was determined to be the “most knowledgeable about family finances.” We use the terms “household,” “individual,” “consumer” and “borrower” interchangeably.

¹⁵ See equation (4) below for a formal definition of the APR. Although the SCF question does not specify a particular definition of “rate of interest”, we use the APR as our benchmark because: a) it has been the standard unit of comparison for borrowing costs in the U.S. since the enactment of Truth in Lending law in 1968; b) it is the rate respondents supply when asked about the most prevalent type of loan, home mortgages. Using alternative benchmarks such as the Effective Annual Rate, which is higher than the APR and may be a better measure of true borrowing costs, does not change the results because we use cross-sectional variation in perceptions; i.e., we use relative and not absolute bias (see equation (8)).

¹⁶ We assume that the monthly installment payments are equal when calculating the actual APR. Different assumptions about payment arrangements do not change the qualitative results that respondents generally underestimate interest rates (even if we assume that the first eleven payments are zero, and the last completely repays the loan). More important, while such transformations change the level measure of misperception they do not alter the cross-sectional ranking in misperception. As noted directly above it is this ranking that provides identification in our empirical tests below.

with other frequent rates corresponding to round repayment totals (\$1300, \$1400, \$1100, etc.). The twenty-fifth percentile is 35% and the seventy-fifth is 81% (\$1500).

The next question in the survey is:

“What percent rate of interest do those payments imply?”

This response is i^p , the *perceived APR*. Figure 1b shows the distribution of perceived APRs. The perceived rate distribution has a lower variance than the actual rate distribution but the perceived rate is still correlated with the actual rate; the correlation is 0.46 among those with actual APRs below the median.

Payment/interest bias is the difference between the perceived and actual APRs. Figure 2a presents a histogram of payment/interest bias in the 1983 SCF. Over 98% of respondents underestimate the actual rate. Roughly twenty percent of respondents give the “simple” or “add-on” rate (e.g., a repayment total of \$1200 yields a perceived rate of 20%).¹⁷ But responses are biased even relative to this rate; those who supply something other than the add-on rate tend to underestimate relative to the add-on (Figure 2b). The size of bias is quite striking, although not integral to our empirical work (which focuses on cross-sectional differences in bias). The median bias is -25 percentage points (2500 basis points), and the mean bias is -38 percentage points.¹⁸ Table 1 shows tabular data on payment/interest bias in both the 1983 and 1977 SCFs. The data show that bias is similar in both surveys, although it is slightly smaller in the 1977 data. We stratify bias into the quintiles that we use to measure *relative* differences in bias for our analysis of whether bias affects decisions.

While we do not know of any more recent representative data measuring payment/interest bias, there is one bit of corroborating contemporary evidence. Following an internal presentation of this paper, a skeptical colleague gave an updated version of the SCF questions to students in a finance class that had recently covered discounting. Of thirty-seven students, all underestimated the APR: one gave a rate above the add-on rate, twelve gave the add-on rate, and the remainder underestimated relative to both the APR and the add-on rate.

¹⁷ The add-on rate does not account for declining principal balances (i.e., for the fact that installment loan repayments include principal as well as interest), and therefore understates the APR. The add-on rate was the prevailing way of quoting loan terms before the enactment of the Truth-in-Lending Act (National Commission on Consumer Finance 1972). Our empirical work treats those supplying the add-on rate differently (by giving them their own intercept) conditional on the absolute level of bias

¹⁸ The Juster and Shay (1964) results allow one to infer something about the size of payment/interest bias. Average bias in their sample of Consumers Union members is substantial (1500 basis points) but smaller than in our samples.

C. New Evidence: Bias on Actual Loans

Both the 1983 and 1977 SCFs also contain self-reported interest rates on *actual* loans: on all installment loans in the 1977 SCF, and on mortgages in the 1983 SCF. This is useful because with self-reported data on principal, maturity and payments, we can calculate the actual APR on each loan, assuming that consumers report non-interest loan terms accurately. This allows us to ask whether consumers also display payment/interest bias on actual loans, and moreover whether payment/interest bias varies with loan maturity (recall that the hypothetical question concerns only a one-year maturity).

Table 2 presents summary data on payment/interest bias on all actual non-mortgage installment loans in the 1977 SCF, and all actual mortgages in the 1983 SCF.¹⁹ The data reveal substantial payment/interest bias on short-term loans; for the shortest-maturity loans actual rates average 30 percent while perceived rates average 13 percent. Payment interest bias on actual loans is positively correlated with payment/interest bias on hypothetical loans. This is evident from the bottom two panels of Table 2.

The other striking result is that bias falls with maturity, and is close to zero for the longest-maturity installment loans and mortgage loans (which themselves tend to have 15-30 year maturities). On mortgage loans virtually everyone is unbiased; 96% provide the correct APR.

D. Summary of the Evidence on Payment/Interest and Future Value Bias

There are three sets of stylized facts on how consumers intuitively perceive the costs and benefits of intertemporal tradeoffs. First, consumers systematically display future value bias in the lab. Second, they systematically display payment/interest bias on both hypothetical and actual loans. Third, the severity of each bias depends on the time horizon. Future value bias is more severe for long-term savings, while payment/interest bias is more severe on short-term loans.

When looking at these facts it is not surprising to see that consumers make mistakes, or even that they make large mistakes. The math of interest rates and future values is complex (as detailed in the next section). The striking thing is that consumers give answers that are *biased*: they almost always underestimate future values, and almost always underestimate loan interest rates. We now ask whether a common cognitive underpinning can explain not only payment/interest bias and future value bias, but also the relationship between each bias and the time horizon being considered.

¹⁹ We discard installment loan responses from 1977 that imply negative interest rates; in all likelihood these are loans with balloon payments, which are not recorded. We also discard mortgages from 1977, because that survey does not identify the size of escrow payments for taxes and insurance in each household's mortgage payment, making calculation of the actual APR impossible.

III. Explaining Payment/Interest and Future Value Bias: Exponential Growth Bias and Other Possibilities

Here we consider several explanations for the pattern of payment/interest and future value bias documented above. In particular we show that exponential growth bias (“EG bias”) provides a parsimonious explanation. EG bias is the tendency of individuals to systematically and dramatically underestimate the growth or decline of exponential series when asked to make intuitive assessments (without calculators).²⁰ Thirty years of research in cognitive psychology establishes that EG bias appears robustly across elicitation methods and contexts (see Web Appendix A for a review).

A. Exponential Growth Bias and Future Value Bias

It is intuitive that someone who underestimates exponential growth will display future value bias. Consider a consumer who saves a present value PV at a periodic interest rate i over time horizon t , with periodic compounding. The future value is:

$$FV = PV(1+i)^t \quad (1)$$

The term $f(i,t) = (1+i)^t$ is an exponential function, and an individual with EG bias will underestimate $(1+i)^t$. Because the future value is just a multiple of that term, there is a straightforward link between EG bias and future value bias. Even a mild degree of EG bias can lead to substantial future value bias; consider a consumer with the following form of EG bias:

$$f(i,t,\theta) = (1+i)^{(1-\theta)t} \quad (2)$$

The θ term parameterizes bias: Unbiased consumers have $\theta=0$ and correctly perceive exponential growth, while those with $0 < \theta < 1$ have EG bias. Figure 3 shows how an EG biased-consumer would perceive future values over different time horizons $t=[1,5,30]$, with bias on the interval $\theta \in [0,0.15]$.²¹ Figure 3 uses $i=7\%$, a benchmark return on equities. Perceived future values are calculated using:

²⁰ We focus on exponentiation rather than on the other mathematical operations involved in borrowing and savings calculations because there is little evidence of biases in basic arithmetic. For reviews of related evidence see Campbell and Xue (2001) and DeStefano and LeFevre (2004)

²¹ This range of parameterized EG bias is actually small relative to that estimated by Eisenstein and Hoch for savings. Eisenstein and Hoch fit the slightly more flexible function $f(i,t,\alpha,\beta) = \alpha(1+i)^{\beta t}$ and estimate $(\hat{\alpha} \cong 0.45, \hat{\beta} \cong 0.50)$. We use smaller values for EG bias because they fit our loan data better. The median θ implied by the hypothetical loan questions used in Figures 1a and 1b is 0.2, and the interquartile range is $[0.14, 0.33]$. The values implied by the actual loan questions from 1977 are smaller on average.

$$FV = PV \cdot f(i, t, \theta) \quad (3)$$

The calculations use annual compounding and PVs that equalize the FV when $\theta = 0$, to facilitate comparison of perceived FVs as EG bias changes. Figure 3 illustrates that EG bias is essentially irrelevant over a one year horizon, and has large effects over a retirement planning (30-year) horizon. We show the effects for a single interest rate to conserve space, but it is evident from (1) and (2) above that the level effects of bias are increasing in the interest rate.

Another parameterization of EG bias is “linear bias,” which is a useful benchmark because it describes a complete failure to account for compounding. The mathematical form for linear bias is $f(i, t) = 1 + it$, meaning that the perceived future value is linear in t . In lab experiments measuring EG bias, perceived future values are often closer to those implied by linear bias than to the true value.

B. Exponential Growth Bias and Payment/Interest Bias

Interest rate formulas also contain exponential functions. The formula relating a periodic interest rate i to a loan amount L , maturity t , and periodic payment m is:

$$m = Li + \frac{Li}{(1+i)^t - 1} \quad (4)$$

This equality contains the same exponential term that appears in the future value formula: $f(i, t) = (1+i)^t$.²² There is no closed-form solution for the periodic rate; it is defined implicitly. If the period is one month, the annual percentage rate (APR) on the loan is equal to $12i$.²³

Although the math is considerably more difficult than for future values, one can also show that EG bias produces payment/interest bias.²⁴ Web Appendix B presents a formal treatment of the issue, proving that EG bias produces payment/interest bias and showing conditions under which bias is greater for short-term loans.

Despite the subtlety of the math involved, the intuition for this result is straightforward. Payment/interest bias is a consequence of failing to account for *declining principal balances* on installment loans. The most common incorrect answer on the hypothetical questions in Section IIC is the add-on interest rate, which represents the true cost of borrowing only if the borrower

²² There are many ways to write the formula in (4); we choose this one to make the link between the saving and borrowing calculations as clear as possible.

²³ The APR is not continuously compounded. The continuously compounded rate, $(1+i)^{12}$, is known as the Effective Annual Rate (EAR). It is not a widely used measure of borrowing costs.

²⁴ We discuss whether this accurately describes the inferences consumers actually make in the next section (or whether, for example, Truth in Lending forcing lenders to disclose APRs renders such inference unnecessary). Here our focus is simply on asking whether EG bias can explain payment/interest bias in the context of the questions in Section II.

