Exponential Growth Bias in an Inflationary World

Bryan Foltice
Butler University

This paper examines the exponential growth bias (EGB), both compound savings questions and in a domain relevant to household finance: inflation-based questions. Here, we test a broad-based sample of 354 adults living in the US initially on estimates for future compound savings and future prices after inflation over time. Here, we find significant EGB in both domains with and without calculators, with significantly higher bias sizes in the inflation questions. After the initial results, each participant completed a short 5 to 10-minute tutorial designed to teach them about EGB. We split the overall participants into two random learning groups: One group was shown how to use interactive charts while the other group learned the formal formula. While we do not find any significant differences of improvements between the two learning groups, we find significantly large decreases in bias sizes in both savings and inflation questions after the tutorial, with and without a calculator, particularly for those who did not know how to make the correct calculation before the tutorial.

Keywords: exponential growth bias, debiasing strategies, financial education

INTRODUCTION AND MOTIVATION

The exponential growth bias (EGB) is a cognitive error in which individuals systematically underestimate the compounding effects of exponential growth (Stango and Zinman, 2009). Exponential growth bias often arises when individuals erroneously rely on linear estimates when interpreting compound growth, leading to misjudgments of financial (savings and debt-based) decisions (Stango and Zinman 2009, Almenberg and Gerdes 2012, McKenzie and Liersch 2011, Soll et al. 2013 Goda et al. 2014, Song 2020), population growth (Wagenaar and Sagaria, 1975, Wagenaar and Timmers, 1979), and the spreading of infectious diseases (Schonger and Sele 2020, Lemmers, Crusius and Gast 2020, Banerjee and Majumdar 2023).

The empirical financial ramifications of the EGB are best documented by Stango and Zinman (2009, p. 2807), who find that households with higher EGB tend to "borrow more, save less, and favor shorter maturities" compared to the less biased households. Levy and Tasoff (2015, p. 545) also find that bias size is "negatively associated with asset accumulation."

Additionally, Foltice and Langer (2017) studied the effects of understanding the exponential savings growth formula with university students in Germany. They found encouraging evidence that individuals who could correctly calculate with a provided calculator made better intuitive savings and amortization (debt-based) estimates when the calculator was not allowed. Their findings were subsequently supported when they tested students in the United States at UCLA (Foltice and Langer, 2018).

This paper follows a similar format to the two previous studies but seeks to analyze a broader sample of adults living in the United States, as opposed to testing only students at top universities. In this study, we initially test 354 adults living in the US on various compound savings questions. We first elicit estimates without the availability of a calculator, when intuition must be utilized, and then with an embedded scientific calculator, which provides the participant with a chance to calculate the correct answers by properly using the exponential growth formula. Consistent with previous studies, we expect to find EGB in the savings domain without a calculator.

This study also attempts to extend the analysis of the exponential growth bias into a new domain that is now highly relevant to household finance: Inflation. With US inflation peaking at 9.1% in June 2022 (Bureau of Labor, 2024), households are experiencing higher prices on various products at a rate not seen since 1981. Cordes, Branger, and Langer (2023) refer to the "inadequate consideration of inflation when making long-term decisions" as the money illusion, arguing that this illusion can have severe financial consequences for future well-being if not addressed. Thus, we aim to identify if this money illusion stems from exponential growth bias. Furthermore, we examine whether participants handle inflation-based growth questions differently from compound growth questions, when both exhibit the same growth pattern.

Thereby, in addition to testing EGB in the savings domain, we test the same participants on inflation-based questions. Similar to the EGB expectations in the savings domain, we expect participants to systemically underestimate the future costs of future items in the inflationary domain. While this has been indirectly examined in previous studies (Cordes, Foltice, Langer, 2019, Cordes, Branger, and Langer, 2023), we seek to directly analyze bias size and impact in this domain.

After capturing initial bias levels in the two aforementioned domains (savings and inflation) with and without a calculator, we provide a short 5–10 minute tutorial designed to teach each participant about the exponential growth bias. Given the immense negative implications of long-term financial decisions stemming from the exponential growth bias, we believe it is crucial to explore ways to effectively mitigate or eliminate these biases.

In our study, we split the overall participants into two random learning groups: Half of the participants complete a short 5–10-minute tutorial that is designed to teach them about EGB and will use interactive learning to visually show (through interactive charts) how savings and inflation affect prices over time, based on assumed interest rates and time (we call this the interactive learning group). Banjerjee and Majumdar (2023) found that intervening with a feedback mechanism designed to inform participants of their EGB successfully improved risky investment decisions and moderated economic expectations. Our interactive learning mechanism aims to mitigate the exponential growth bias in both domains (savings and inflation) across both treatments (with and without a calculator).

The other half of the participants will also complete a short 5–10-minute tutorial designed to teach them about EGB, which will subsequently show them how to make the formal calculation for the two domains (we will call this the formula learning group). Foltice and Langer (2017) found encouraging evidence with University students that the compound savings formula can be quickly learned and applied, not only reducing their bias size in savings questions with calculator, but also without a calculator and in other (loan amortization) domains. Here, we seek to evaluate the effectiveness of this formula learning with a broad sample of US adults. After completing the tutorial, we will retest an abbreviated version of the questions in the two domains, both with and without a calculator.

We believe that the findings of this survey will provide us with insights into how people tend to underestimate the future value of compound savings growth, as well as the growth of future prices, based on inflation expectations. Additionally, we will gain further insights into how a broader group of individuals (compared to previous studies, which mainly consisted of university students) estimates exponential growth and learn whether they can generate correct answers using a calculator. Ultimately, we aim to investigate the effectiveness of the two types of learning in enhancing intuitive estimates (without a calculator) and calculations (with a calculator).

In this paper, we find significant EGB in both the savings and inflation domains, with and without calculators, and observe significantly higher bias sizes in the inflation questions. We also find that the ability to make a correct calculation drives less bias in their estimates without a calculator.

After the tutorials, we observed significantly large decreases in bias sizes in both savings and inflation questions, both with and without a calculator, particularly among those who did not know how to make the correct calculation before the tutorial. However, we do not find any significant differences of improvements between the interactive and formula learning groups.

METHODOLOGY

This online survey was designed to be completed in approximately 30-40 minutes, in total. The overall average (median) completion time was 37.97 (32.37) minutes for an intended representative sample of US-based adults, as conducted through the Prolific survey platform. Overall, 354 participants completed the survey, with 180 (174) in the experiential (equation) learning group. Each participant was given $8 for completing this survey. Ideally, we would've preferred to add a performance-based incentive for accuracy and improvement but were unable to program this functionality in Prolific. A full breakdown of the participant demographics is displayed in Table 1.

TABLE 1
OVERALL PARTICIPANT DEMOGRAPHIC BREAKDOWN:
SHOWN AT THE OVERALL AND GROUP (TUTORIAL) LEVELS

Description	Overall	Experiential	Equation
Participants	354	181	173
Gender			
Male	47.2%	48.1%	46.2%
Female	50.0%	49.8%	50.3%
Other/No Answer	2.8%	2.1%	3.5%
Age			
Average Age (in years)	38.04	38.28	37.79
18–34	47.2%	48.3%	46.0%
35–54	41.5%	38.3%	44.8%
55 and over	11.3%	13.3%	9.2%
Race			
White/Caucasian	67.2%	68.5%	65.9%
Black/African American	17.2%	19.9%	14.5%
Asian	9.0%	6.6%	11.6%
Other	6.5%	5.0%	8.1%
Highest Educational Level			
Higher School or GED	13.6%	12.8%	13.3%
Some College (no degree)	18.6%	18.2%	19.1%
Associate's degree	7.1%	6.6%	7.5%
Bachelor's Degree	38.4%	38.7%	38.2%
Master's Degree	18.1%	18.8%	17.3%
Doctorate or Professional	4.2%	3.9%	4.6%
Annual Income			
<$50,000	36.2%	33.2%	39.3%
$50,000-$99,999	38.7%	42.5%	34.7%
$100,000-$149,999	15.3%	16.6%	13.8%
$150,000 or more	8.5%	7.2%	9.8%
No Answer	1.4%	0.6%	2.3%
Self-Stated Attributes (1-5 Scale)			
No Comp. Growth Aware	3.33	3.33	3.33
Good Saver	3.09	3.05	3.14
Good with Numbers	3.01	2.97	3.05

Next, the two main questions (savings and inflation) are shown below as they were displayed in the survey:

- **Savings Question**
  You currently have a balance of **$30,000** in your account. You leave this money in your savings account for **X years** at a constant annual interest rate of **X%**. Assume no additional deposits or withdrawals. Interest is compounded annually and reinvested into the account.
  Based on the above information, estimate your total account balance after **X** years. Please provide your best estimate.
- **Inflation Question**
  Today, an average car costs $30,000. Over the next X years, inflation is expected to run an average of X% each year. Assume that the average cost of a car is in line with the rate of inflation.
  Please estimate the expected cost of a car in **X years**.

Each participant began the survey by completing a total of eight estimates (four savings and four inflation) without a calculator, followed by four additional estimates (two savings and two inflation) using a provided online scientific calculator. Upon completing these questions, each participant was given a short 5-10 minute tutorial designed to teach them about the exponential growth bias and demonstrate how to either use a downloadable interactive spreadsheet (Interactive Learning Group) or calculate the actual equation using the provided calculator (Formula Learning Group). Details of the two tutorials are provided in Appendix 1 (Interactive Learning Tutorial) and Appendix 2 (Equation Learning Tutorial).

Upon completion of the tutorial, each participant was asked to close their calculators and spreadsheets and make four additional estimates (2 savings and 2 inflation).[2] After that, participants completed the final four estimates/calculations (two savings and two inflation) using their provided calculator or a downloadable spreadsheet. Participants provided feedback and demographic information in the final section of the overall survey.

Table 2 shows the overall survey design and question matrix including the parameters used for each of the questions before (and after in "()") the tutorial: 8 (4) total estimates – 4 (2) Savings, 4 (2) Inflation.

TABLE 2
OVERALL SURVEY DESIGN AND QUESTION MATRIX OUTLINE

1. Pre-Tutorial – No Calculator Matrix			**2. Pre-Tutorial – With Calculator Matrix**		
8 Estimates	Rate	Time (2x2)	4 Estimates	Rate	Time (1x2)
4 Savings	5%	15	2 Savings	5%	30
4 Inflation	10%	30	2 Inflation	10%	
3. 5–10 Minute Tutorial (Group A: Interactive Learning/Group B: Formula Learning)					
4. Post-Tutorial – No Calculator Matrix			**5. Post-Tutorial – With Calculator Matrix**		
4 Estimates	Rate	Time (1x2)	4 Estimates	Rate	Time (1x2)
2 Savings	5%	30	2 Savings	5%	30
2 Inflation	10%		2 Inflation	10%	
6. Feedback and Demographics Information					

ANALYSIS: PRE-TUTORIAL RESULTS

To analyze the size of exponential growth bias, we utilize the "Theta measure" from Foltice and Langer (2017), which captures the size of exponential growth bias in both savings and inflation domains. This measure captures the linear treatment/estimate of compound growth in all various parameters and domains as a θ measure of 1.00 and identifies the perfect calibration for each question as 0.00. Formally, the accumulation function $\breve{f}_{i,t}(\theta) = (t \cdot i)^{(\theta)} \cdot ((1+i)^t - 1)^{(1-\theta)} + 1$ captures the desired properties:

$$\breve{f}_{i,t}{}^{-1}((1+i)^t) = 0 \tag{1}$$

and

$$\breve{f}_{i,t}{}^{-1}(1 + t \cdot i) = 1 \tag{2}$$

and is able to assign a bias size θ to any answer *FV>PV* in the savings and inflation domains.

Using this measure, we can analyze the average and median bias size for the overall group, as well as for individuals in both treatments (without vs. with a calculator, as well as pre- and post-learning). This includes improvements in bias reduction after the learning both with and without a calculator. In the initial analysis, we report median values, as the distribution of bias sizes showed evidence of a non-normal distribution, based on the Shapiro-Wilk test.

TABLE 3
OVERALL GROUP LEVEL DESCRIPTIVE STATISTICS FOR PRE-TUTORIAL SAVINGS QUESTIONS, SORTED BY QUESTION AND ROUND

Pre-Tutorial Results		**Round 1 (without calculator)**			**Round 2 (with calculator)**			
Question (N=354)	**Actual**	**Median**	**Medianθ**	**Biased†**	**Median**	**Medianθ**	**Biased†**	**Correct°**
Savings; 5%, 15 yrs.	$62,368	$55,000	0.71***	74.1%				
Savings; 10%, 15 yrs.	$125,317	$79,500	0.87***	83.4%				
Savings; 5%, 30 yrs.	$129,658	$81,500	0.83***	78.6%	$124,242	0.07***	49.9%	36.2%
Savings; 10%, 30 yrs.	$523,482	$125,000	0.97***	91.3%	$300,000	0.35***	57.7%	38.7%
All Savings (N=1416)			**0.85*** **	**81.8%**		**0.21*** **	**61.4%**	**37.5%**
Inflation; 5%, 15 yrs.	$62,368	$52,500	1.00***	78.9%				
Inflation; 10%, 15 yrs.	$125,317	$75,000	1.00***	84.8%				
Inflation; 5%, 30 yrs.	$129,658	$75,000	1.00***	85.1%	$88,214	0.68***	59.2%	28.5%
Inflation; 10%, 30 yrs.	$523,482	120,000	1.00***	92.1%	$150,000	0.83***	63.4%	30.5%
All Inflation			**1.00*** **	**85.2%**		**0.75*** **	**67.7%**	**29.5%**
All Medium-Term			**0.90*** **	**80.3%**				
All Long-Term			**0.95*** **	**86.6%**		**0.47*** **	**64.6%**	**33.5%**

† Answers less than actual answer yielding a θ greater than 0.00.
° Answers yielding a θ between -0.0149 and 0.0149.
* <10% - ** <5% - *** <1% Statistical Significance (Wilcoxon signed rank test)

As shown in Table 3, the median bias size in the four savings questions ranges from 0.71 up to 0.97, with an overall median bias size of 0.85 for all estimates without a calculator. All median bias sizes are statistically significantly different from 0 based on the Wilcoxon signed-rank test. Nearly 82% of the savings estimates underestimated the actual compound growth.

The median bias size for all four inflation questions without a calculator, depicted in Table 3, is the exact linear estimate (1.00 bias size), with over 85% of the estimates underestimating the actual inflationary growth.

When provided with an embedded scientific calculator in the next round of questions, bias size is reduced, but not eliminated, in both domains. Again, the median bias size for both savings questions was less (0.21) than the median bias size for inflation-based questions (0.75). These smaller median bias sizes were driven by a small population of participants who were able to generate the correct answers with the calculator before the tutorial. Based on our definition of "correct" calculations, where we allow for rounding to the nearest thousand (for example, \$523,000 instead of \$523,482.37), 37.5% of the savings and 29.5% of the inflation-based questions were calculated correctly. In the next section, we will analyze whether there is a statistically significant bias in the size of inflation-based questions compared to savings questions.

TABLE 4
OVERALL AND INDIVIDUAL DESCRIPTIVE STATISTICS AND RESULTS SUMMARY, SORTED BY DOMAIN, AND PRE-TUTORIAL TREATMENT

Pre-Tutorial Results	**No Calculator**			**With Calculator**		
Overall (Median)	**Savings**	**Inflation**	**Difference**	**Savings**	**Inflation**	**Difference**
All (N=1416)	0.86***	1.00***	0.14***	(N=708) 0.18***	0.78***	0.60***
All Med-Term (N=708)	0.86***	1.00***	0.14***			
All Long-Term (N=708)	0.94***	1.00***	0.06***			
Individual Level (no correct calculations in round 2 – N=188)						
Median θ (N=752)	1.00***	1.24***	0.24***	(N=376) 1.00***	1.00***	0.00**
Average θ (N=752)	1.22***	1.45***	0.23***	(N=376) 1.01***	1.17***	0.16*
Individual Level (at least one correct calculation in round 2 – N=166)						
Median θ (N=664)	0.30***	0.71***	0.41***	(N=332) 0.00***	0.00***	0.00***
Average θ (N=664)	0.38***	0.64***	0.26***	(N=332) 0.08***	0.20***	0.12***
Differences Level Between Groups						
Median θ	-0.75***	-0.63***		-1.00***	-1.00***	
Average θ	-0.75***	-0.75***		-0.93***	-0.96***	

Participants were separated by individuals who made one or more correct calculations with a calculator (N=166) and those with zero correct calculations (N=188).
Wilcoxon matched-paired signed-rank test was used for the median θ analysis (hypothesized median of 0). The analysis of median θ differences, used a Wilcoxon rank-sum test. For the average θ analyses, a one-sample t-test is used to analyze the difference from 0.00 and a two-sample t-test is employed for the differences of average bias sizes. For all tests, * $p < .10$, ** $p < .05$, *** $p < .01$.

In Table 4, we compare the median and average bias sizes of savings and inflation questions in both pre-tutorial treatments (without and with a calculator). In the top section, which analyzes the overall results, we find significantly higher bias sizes in the inflation-based questions in both treatments, with and without a calculator. The overall difference in bias size is 0.60 with a calculator, demonstrating the first evidence that participants overall underestimated inflation growth more than savings growth.

Next, we divide participants who were able to provide at least one correct calculation using the embedded online calculator from those who did not. Once again, we analyze the median bias sizes between domains (savings and inflation) and treatments (without and with a calculator). First, we find that the group that could not provide the correct calculation post-median and average bias sizes ranged from 1.00 to 1.45 without a calculator. In other words, this group underestimated compound savings and inflation at and less than the linear estimate. They also post significantly higher bias sizes in the inflation-based questions. With the provided calculator, the group who could not make a correct calculation maintained median and average bias sizes ranging from 1.00 to 1.17, which are at or below the linear answers.

On the other hand, we detect significantly lower median and average bias sizes between the groups that could and could not calculate the correct answer, even in the non-calculator treatment (0.63 to 0.75 less). This confirms the initial findings of Foltice and Langer (2017), who found evidence in university students that the ability to calculate the correct answers assisted with making less biased intuitive estimates. In the calculator treatment, the overall biases for this group are not completely eliminated, as the median and averages were shown to be significantly different from 0. Additionally, the inflation-based median and average bias sizes are significantly higher when using a calculator, as indicated by the Wilcoxon rank-sum (median) and two-sample t-tests. Finally, the group with at least one correct calculator posted median and average biases 0.93 to 1.00 less in both savings and inflation-based questions.

In the next section, we analyze the drivers of pre-tutorial bias sizes in both domains without a calculator. Here, we employ a quantile regression, which is designed to analyze nonparametric results.[3] For independent variables used in regressions (1, 2, and 4), we include gender (Male – 0, Female- 1), education level (High School or GED – 1, Some College (no degree) – 2, Associate degree - 3, Bachelor's Degree – 4, Master's Degree – 5, Doctorate or Professional – 6), age (years), Income (<$50,000 – 1, $50,000-$99,999 - 2, $100,000-$149,999 – 3, $150,000 or more – 4), and race (White/Caucasian - 0, Others – 1). For regressions 2-4, we include three self-stated attributes that were elicited on a 1 to 5 scale by the following statements:

1. No Previous Knowledge – "I had no previous compound growth knowledge before this survey."
2. Good Saver – "I am a good saver."
3. Good with numbers. "I am good at math and numbers."

For the fourth regression, we include a variable with the number of "correct calculations" made, out of a possible four, with the calculator.

TABLE 5
QUANTILE REGRESSION PRE-TUTORIAL RESULTS WITH NO CALCULATOR, BY DOMAIN

	Pre-Tutorial – Savings (w/o calculator)				**Pre-Tutorial – Inflation (w/o calculator)**			
Participant Characteristics	(1s)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Intercept	0.804***	1.029***	0.797***	1.251***	1.178***	1.150***	1.137***	1.280***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Female	0.253***		0.143***	0.045	0.191***		0.145**	0.065
	(0.000)		(0.008)	(0.405)	(0.001)		(0.025)	(0.357)
Education	-0.062***		-0.031	-0.034*	-0.039*		-0.030	-0.027
	(0.004)		(0.118)	(0.084)	(0.069)		(0.208)	(0.285)
Age	0.001		0.004*	0.002	-0.002		-0.002	-0.028
	(0.650)		(0.096)	(0.395)	(0.330)		(0.547)	(0.324)
Income	-0.028		0.018	0.019	-0.038*		-0.036	-0.032
	(0.176)		(0.327)	(0.301)	(0.060)		(0.102)	(0.185)
Race	-0.056		-0.053	-0.091	-0.067		-0.015	-0.121*
	(0.380)		(0.349)	(0.104)	(0.285)		(0.823)	(0.095)
Attributes								
No Previous Knowledge		0.097***	0.097***	0.023		0.081***	0.085***	0.073***
		(0.000)	(0.000)	(0.243)		(0.000)	(0.000)	(0.005)
Good Saver		-0.064***	-0.045**	-0.042*		-0.023	-0.007	0.005
		(0.005)	(0.045)	(0.057)		(0.352)	(0.804)	(0.854)
Good with Numbers		-0.128***	-0.104***	-0.042*		-0.115***	-0.093***	-0.060**
		(0.000)	(0.000)	(0.057)		(0.000)	(0.000)	(0.030)
Correct Calculations				-0.157***				-0.171***
				(0.000)				(0.000)
N (observations)	1416	1416	1416	1416	1416	1416	1416	1416

For all regressions, * p < .10, ** p < .05, *** p < .01

At first glance in Table 5, females appear to have provided more biased estimates in regressions (1) and (3), but the effect is eliminated (statistically speaking) in regression (4), when the "correct calculations" variable is included. The only other demographics-based characteristic that showed statistical significance was a decrease in bias size as education increased. Based on our results, age, income, and race do not appear to have any statistically significant effect on the size of bias in either the savings or inflation domains.

On the other hand, self-stated attributes appear to have a significant effect on bias size, with no previous knowledge of compounding growth driving increases in bias size for both savings and inflation-based questions. Meanwhile, individuals stating that they were good savers and good at math/numbers displayed significantly lower bias sizes in both the savings and inflation domains. Finally, correct calculations show significantly lower bias sizes in both domains without a calculator, adding more evidence to the ability to calculate compound growth, which assists in making better intuitive estimates.

ANALYSIS: POST-TUTORIAL RESULTS

Next, we examine the effectiveness of the tutorials as it relates to bias size. The details of each tutorial can be found in Appendix 1 (Interactive Learning Tutorial) and Appendix 2 (Equation Learning Group).

TABLE 6
POST TUTORIAL RESULTS: BIAS SIZES BY DOMAIN, TREATMENT AND GROUP LEVELS

Post Tutorial Results	No Calculator		With Calculator		
Both Groups	**Median**	**Average**	**Median**	**Average**	**Correct**
All Four Questions (N=1416)	0.13	-0.08*	0.00***	0.23***	64.0%
Two Savings Questions (N=708)	0.66	0.03	0.00***	0.15***	66.8%
Two Inflation Questions (N=708)	0.00**	-0.19*	0.00***	0.30***	61.6%
Interactive Learning Group					
All Four Questions (N=724)	0.13	-0.05	0.00***	0.20***	68.0%
Two Savings Questions (N=362)	0.79	0.11	0.00***	0.14***	69.9%
Two Inflation Questions (N=362)	0.00**	-0.20**	0.00***	0.25***	65.7%
Equation Learning Group					
All Four Questions (N=692)	0.13	-0.11*	0.00***	0.26***	60.5%
Two Savings Questions (N=346)	0.64	-0.04	0.00***	0.16***	63.6%
Two Inflation Questions (N=346)	0.00**	-0.17**	0.00***	0.35***	57.2%
Differences Between Groups					
All Four Questions (N=1416)	0.00	-0.06	0.00	0.06	-7.5%***
Two Savings Questions (N=708	-0.15	-0.15	0.00	0.02	-6.3%***
Two Inflation Questions (N=708)	0.00	0.03	0.00	0.10	-8.5%***

Wilcoxon matched-paired signed-rank test was used for the median θ analysis (hypothesized median of 0). The analysis of median θ differences, used a Wilcoxon rank-sum test. For the average θ analyses, a one-sample t-test is used to analyze the difference from 0.00 and a two-sample t-test is employed for the differences of average bias sizes. For all tests, * $p < .10$, ** $p < .05$, *** $p < .01$.

As shown in Table 6, we find substantially lower bias sizes after the tutorial, not only with the available calculator but also when we test estimates without it. Interestingly, the average bias size of all questions and many of the inflation-based questions is significantly different from 0, but in the negative direction (that is, the average overestimates these questions).

Overall, 64.0% of all questions with a calculator were correctly calculated and answered; however, the median bias size still maintains a significant difference from zero. The median bias sizes with a calculator are all 0.00 and the averages are slightly positive, ranging from 0.14 to 0.35, suggesting that the EGB was not completely eliminated. However, as we will further investigate in the next section, these biases are lower than the pre-tutorial averages across both domains and treatments.

When we compare median and average bias sizes between the two learning groups, we find no statistically significant differences in either domain or treatment. The only significant difference found was the number of correct answers posted were 7.5% less in the formal equation learning group. In the final section of the analysis, we examine the results of participants who did not generate any correct answers with a calculator prior to the tutorial.

TABLE 7
PRE- AND POST-TUTORIAL RESULTS OF THE PARTICIPANTS WITH NO CORRECT CALCULATIONS BEFORE THE TUTORIAL

No Calculator	**Pre-Tutorial**		**Post-Tutorial**			
Both Groups	**Median**	**Average**	**Median**	**Average**	**Diff. (Med.)**	**Diff. (Avg.)**
All Savings Questions (N=752)	1.00***	1.22***	0.74	0.34***	0.26***	0.88***
All Inflation Questions (N=752)	1.24***	1.45***	0.35	0.24***	0.89***	1.20***
Interactive Group	**Median**	**Average**	**Median**	**Average**	**Diff. (Med.)**	**Diff. (Avg.)**
All Savings (N=384/192)	1.00*	1.26***	0.94	0.41***	0.06***	0.86***
All Inflation (N=384/192)	1.24***	1.40***	0.35	0.21*	0.89***	1.19***
Equation Group	**Median**	**Average**	**Median**	**Average**	**Diff. (Med.)**	**Diff. (Avg.)**
All Savings (N=368/184)	1.00***	1.17***	0.64	0.27**	0.36***	0.90***
All Inflation (N=368/184)	1.24***	1.49***	0.35	0.28***	0.89***	1.22***
Difference Between Groups	**Median**	**Average**	**Median**	**Average**		
All Savings Questions (N=368)	0.00	-0.09	-0.30	-0.13		
All Inflation Questions (N=368)	0.00	0.09	0.00	0.07		

With Calculator	**Pre-Tutorial**		**Post-Tutorial**			
Both Groups	**Median**	**Average**	**Median**	**Average**	**Diff. (Med.)**	**Diff. (Avg.)**
All Savings Questions (N=376)	1.00***	1.01***	0.00***	0.22***	1.00***	0.79***
All Inflation Questions (N=376)	1.00***	1.17***	0.00***	0.46***	1.00***	0.71***
Interactive Group	**Median**	**Average**	**Median**	**Average**	**Diff. (Med.)**	**Diff. (Avg.)**
All Savings Questions (N=192)	1.00***	1.02***	0.00***	0.17*	1.00***	0.85***
All Inflation Questions (N=192)	1.00***	1.19***	0.00***	0.35***	1.00***	0.84***

Equation Group	Median	Average	Median	Average	Diff. (Med.)	Diff. (Avg.)
All Savings Questions (N=184)	1.00***	1.00***	0.00***	0.27***	1.00***	0.73***
All Inflation Questions (N=184)	1.00***	1.14***	0.00***	0.58***	1.00***	0.56***
Difference Between Groups	**Median**	**Average**	**Median**	**Average**		
All Savings Questions (N=368)	0.00	-0.02	0.00	0.10		
All Inflation Questions (N=368)	0.00	0.05	0.00	0.23**		

Wilcoxon matched-paired signed-rank test was used for the median θ analysis (hypothesized median of 0). The analysis of median θ differences, used a Wilcoxon rank-sum test. For the average θ analyses, a one-sample t-test is used to analyze the difference from 0.00 and a two-sample t-test is employed for the differences of average bias sizes. For all tests, * p < .10, ** p < .05, *** p < .01

As shown in Table 7, both groups experience a significant improvement in their overall median average bias levels, both with and without a calculator, after the tutorial. In the treatment without a calculator, the median bias level are not significantly difference from zero in both groups. While the average bias sizes are still greater than zero, we find improvements in averages ranging from 0.88 to 1.20, which is equivalent to the difference between the linear bias estimate and the correct answer. Between learning groups, there appears to be no significant differences in any of the domains or treatments.

With a calculator, we detect similarly strong improvement in both groups, ranging from 0.56 up to 1.00. The only statistically significant difference we found was a higher average bias size in the inflation-based questions after the tutorial. Overall, these stark improvements in the group that previously demonstrated no ability to make the correct calculation before the tutorial provide encouraging evidence of the positive impact a small learning intervention can have on reducing individuals' biases, both with the calculator and without it, when intuition must be utilized.

DISCUSSION AND CONCLUSION

This paper examines the exponential growth bias (EGB) in not only compound savings questions, but also in similar inflation-based questions, which have recently become more relevant and important for individuals to understand.

Here, we initially test a broad-based sample of 354 adults living in the US, both with and without an embedded scientific calculator, on various estimates for future compound savings and future prices after inflation over time. We find significant EGB in both domains with and without calculators, with significantly higher bias sizes in the inflation questions. We also find that the ability to make a correct calculation drives less bias in their estimates without a calculator. We also analyze other various characteristics and attributes to better understand the drivers of EGB size.

We believe that these findings highlight the importance of learning about exponential growth and how it can not only eliminate exponential growth bias with the aid of a provided calculator, but also significantly reduce this bias in intuitive estimates, even across various domains. We also observed a need to incorporate the effects of inflation on future prices as they consider long-term financial decisions.

After the initial results, each participant completed a brief 5- to 10-minute tutorial designed to educate them about EGB. We then split the overall participants into two random learning groups: Half of the participants are shown how to use interactive charts while the other half learn the formal formula. While we do not find any significant differences in improvement between groups, we observe significantly large decreases in bias sizes in both savings and inflation questions after the tutorial, both with and without a calculator, particularly among those who did not know how to make the correct calculation before the tutorial.

We believe these results to be encouraging, as the learning interventions (i.e. the tutorials) appeared to have a large impact in a short period for a broad sample of adults living in the US. One limitation of this study is that we were unable to test any long-term retention of these learnings. It would be helpful in future research to better understand the retention quality of these tutorials over time. Additionally, we would like to better understand the savings, investments, and debt implications that these learnings could potentially have on individuals and their households.

ACKNOWLEDGEMENT

This project was funded by the Holcomb Research Grant at Butler University in Indianapolis, Indiana and received IRB approval on March 4, 2023.

ENDNOTES

1. Two participants were eliminated from the sample for posting actual answers in this section.
2. Similar results are found when using an OLS regression with this data sample, though the quantile regressions consistently yield higher r-squared values.

REFERENCES

Almenberg, J., & Gerdes, C. (2012) Exponential growth bias and financial literacy. *Applied Economics Letters*, *19*(17), 1693–1696.

Banerjee, R., & Majumdar, P. (2023). Exponential growth bias in the prediction of COVID-19 spread and economic expectation. *Economica*, *90*(358), 653–689.

Benzion, U., Granot, A., & Yagil, J. (1992). The valuation of the exponential function and implications for derived interest rates. *Economics Letters*, *38*(3), 299–303.

Bureau of Labor Statistics. (2024). *12-month percentage change, Consumer Price Index, selected categories.* Retrieved April 2, 2024 from https://www.bls.gov/charts/consumer-price-index/consumer-price-index-by-category-line-chart.htm

Cordes, H., Branger, N., & Langer, T. (2023). Experimental Exploration of Money Illusion in Long-term Financial Decision Making. *SSRN 4326767*.

Cordes, H., Foltice, B., & Langer, T. (2019). Misperception of exponential growth: Are people aware of their errors? *Decision Analysis*, *16*(4), 261–280.

Foltice B., & Langer, T. (2017) In equations we trust? Formula knowledge effects on the exponential growth bias in household finance decisions. *Decision Analysis*, *14*(3), 170–186.

Foltice, B., & Langer, T. (2018). Exponential growth bias matters: Evidence and implications for financial decision making of college students in the USA. *Journal of Behavioral and Experimental Finance*, *19*, 56–63.

Goda, G.S., Levy, M.R., Manchester, C.F., Sojourner, A., & Tasoff, J. (2015). *The role of time preferences and exponential-growth bias in retirement savings* (No. w21482). National Bureau of Economic Research.

Keren, G. (1983) Cultural differences in the misperception of exponential growth. *Perception Psychophysics*, *34*(3), 289–293.

Lammers, J., Crusius, J., & Gast, A. (2020). Correcting misperceptions of exponential coronavirus growth increases support for social distancing. *Proceedings of the National Academy of Sciences*, *117*(28), 16264–16266.

McKenzie, C.R.M., & Liersch, M.J. (2011) Misunderstanding savings growth: Implications for retirement savings behavior. *Journal of Marketing Research*, *48*(SPL), 1–13.

Schonger, M., & Sele, D. (2020). How to better communicate the exponential growth of infectious diseases. *PLoS One*, *15*(12), e0242839.

Soll, J.B., Keeney, R.L., & Larrick, R.P. (2013). Consumer misunderstanding of credit card use, payments, and debt: Causes and solutions. *Journal of Public Policy & Marketing*, *32*(1), 66–81.
Song, C. (2020). Financial illiteracy and pension contributions: A field experiment on compound interest in China. *The Review of Financial Studies*, *33*(2), 916–949.
Stango, V., & Zinman, J. (2009). Exponential Growth Bias and household finance. *Journal of Finance*, *64*(6), 2807–2849.
Wagenaar, W.A., & Sagaria, S.D. (1975). Misperception of exponential growth. *Attention Perception Psychophysics*, *18*(6), 416–422.
Wagenaar, W.A., & Timmers, H. (1979). The pond-and-duckweed problem: Three experiments on the misperception of exponential growth. *Acta Psychiatrica*, *43*(3), 239–251.

APPENDIX 1: EXPONENTIAL GROWTH TUTORIAL (INTERACTIVE LEARNING GROUP)

Did you Know? Most people have a tendency to think in linear terms when making estimates and severely underestimate the impact of compound/exponential growth. This "exponential growth bias" (or EGB) refers to the tendency of individuals to underestimate or neglect the potential magnitude and consequences of exponential growth over time.

In finance, we see exponential growth in our savings/investments over time. Understanding how your money grows over long periods of time motivates us to save more money and borrow less.

This tutorial is designed to show you how compound savings grows over time. Please open the "Compound Growth Calculators" File and let's go to the Compound Savings Growth tab on the far left.

Try it!!! Go ahead and plug in various interest rates and number of years (up to 50 years) and notice how the growth compounds over time.

Note that the longer you are invested, the future values increases dramatically. Higher interest rates also have a large impact on the future growth.

Now, you try...Using the open Spreadsheet, please answer the following question.

You currently have a balance of $30,000 in your account.

You leave this money in your savings account for 32 years at a constant annual interest rate of 8%.

Assume no additional deposits or withdrawals. Interest is compounded annually and reinvested into the account.

Based on the above information, estimate your total account balance after 32 years.

Did you get $352,112.49?

Tutorial Part 2 - Did you Know? Exponential growth can work against us in finance: Inflation increases the costs of goods and services exponentially over time. That means inflation increases the price of the products we buy and services we pay for the same way our savings/investments increase over time.

Because of the exponential growth bias (EGB), we tend to underestimate how much products and services will cost in the future after inflation.

The Good News: The growth for future costs/products is the same as saving. Please go to the Compound Growth Calculators file again and click the middle tab called, "Future Costs After Inflation".

Once again, test out various inflation rates over different time periods and notice the similar dramatically higher future values when the time is increased as well as the inflation rates.

Now, you try it! Using the new spreadsheet, please answer the following inflation-based question. Today, an average car costs $30,000.

Over the next 32 years, inflation is expected to run an average of 6% each year.

Assume that the average cost of a car is in line with the rate of inflation. Please estimate the expected cost of a car in 32 years.

Did you get $193,601.60?

APPENDIX 2: EXPONENTIAL GROWTH TUTORIAL (EQUATION LEARNING GROUP)

Did you Know? Most people have a tendency to think in linear terms when making estimates and severely underestimate the impact of compound/exponential growth. This "exponential growth bias" (or EGB) refers to the tendency of individuals to underestimate or neglect the potential magnitude and consequences of exponential growth over time.

In finance, we see exponential growth in our savings/investments over time. Understanding how your money grows over long periods of time motivates us to save more money and borrow less. With a little math, calculating exponential growth is relatively easy! Here's the equation: FV = PV*(1+r)^t
To calculate future value (FV), you take:

1. + the interest rate (r)
2. Take the sum of step 1 and hit the "y^x" button on your calculator and then type in the number of years (t). On the Google scientific calculator, this button is directly to the left of the "0" button.
3. Take that number and multiply it by your present value/current savings (PV)

Now, you try...

You currently have a balance of **$30,000** in your account.

You leave this money in your savings account for **<u>32</u>** years at a constant annual interest rate of **<u>8%</u>**. Assume no additional deposits or withdrawals. Interest is compounded annually and reinvested into the account.

Based on the above information, estimate your total account balance after **<u>32 years</u>**. Using your <u>Google scientific calculator</u>, Please provide your best estimate.

Did you get **<u>$352,112.49?</u>** That's the correct answer!

Tutorial Part 2 - Did you Know? Exponential growth can work against us in finance: Inflation increases the costs of goods and services exponentially over time. That means inflation increases the price of the products we buy and services we pay for the same way our savings/investments increase over time.

Because of the exponential growth bias (EGB), we tend to underestimate how much products and services will cost in the future after inflation.

The Good News: The calculation for future costs/products is the same as saving: FV = PV*(1+r)^t

The only difference is that "r" is the inflation rate and "PV" is the present cost of a product.

Now, you try it!

Today, an average car costs **$30,000.**

Over the next **<u>32 years,</u>** inflation is expected to run an average of **<u>6%</u>** each year.

Assume that the average cost of a car is in line with the rate of inflation. Please estimate the expected cost of a car in **<u>32 years.</u>**

Here's a link to the <u>Google scientific calculator</u>.

Did you get **<u>$193,601.60?</u>** That's the correct answer!