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Pitfalls of Compound Interest Effect: Private Investors Underestimate Loss Risks of Financial Products

by Christian Zankiewicz

People are investing their life savings in financial products, for instance, to provide for their retirement and, in doing so, they are making their future financial situation almost entirely dependent on the success of these investments. The financial sector promotes numerous investment opportunities with widely varying levels of risk—from the classic private pension insurance to high-risk equity funds. To help investors select a product suitable for them and to safeguard against financial losses, policy-makers have prescribed standardized and comprehensive product leaflets and consulting protocols. But is that enough? So as not to make poor investment decisions, investors also need sufficient knowledge of the financial issues, which, for example, allow them to accurately assess the effects of compound interest on an investment and the risk of loss. This seems to be the problem area, as indicated by the results of a behavioral experiment conducted by DIW Berlin in cooperation with the Humboldt-Universität zu Berlin: most of the participants selected misunderstood the effect of compound interest—and consequently seriously underestimated the investment risk.

Compound interest is interest calculated on capitalized interest from previous periods. In the case of constant positive interest, this results in exponential asset growth. As early as the nineteenth century, the physiologist Ernst Heinrich Weber discovered that human senses perceive exponential increases in the intensity of physical stimuli, such as light intensity, as linear increases and consequently underestimate their intensity. Surprisingly, there is also evidence of this misperception with regard to exponential growth processes in financial mathematics: for example, participants in a scientific study were asked to provide the final value of a seven-percent interest rate applied over ten periods. Instead of providing the correct answer of 97-percent growth, a considerable proportion of respondents thought it was just 70 percent.¹ Measured according to the simplicity of the question, this is a serious misperception which is particularly relevant for budgetary decisions regarding loans, savings, or investments.

The literature on behavioral economics provides evidence that such a misconception of economic growth processes stems from what are known as heuristics: these are rules of thumb used to simplify a given task to the extent that the given individual is able to solve it more quickly, or indeed solve it at all. One heuristic relating to interest calculations is the linearization rule of thumb, according to which investors erroneously disregard the additional interest on interest from previous periods (see box).²

¹ V. Stango and J. Zinman, „Exponential growth bias and household finance,” *Journal of Finance* 64 (6)(2009): 2807–2849.

² See, inter alia, H. Chen and A. R. Rao, „When two plus two is not equal to four: Errors in processing multiple percentage changes,” *Journal of Consumer Research* 34(2007): 327–340 and F. Christandl and D. Fetchenhauer, „How laypeople and experts misperceive the effect of economic growth,” *Journal of Economic Psychology* 30(2009): 381–392.

Investment Risks: A Hypothetical and a Real Example

While, given constant positive interest, a linearization of compound interest will always result in investors underestimating the future value of an investment, this behavior can lead to investors dangerously overestimating the future value of an investment in a more realistic investment environment: if the interest rate is not constantly positive but instead fluctuates at random and may become negative, it is often very difficult for small private investors in particular to estimate the risk of loss.

The hypothetical example (hence forth pension scenario) of small private investors making financial provisions for retirement with the intention of cashing in on their investment in 12 years' time illustrates this situation: the small investors are advised to make an investment which may increase in value by 70 percent within a one-year period (consequently demonstrating positive interest) but might also drop by 60 percent (thus yielding negative interest). With this investment, both developments are equally likely. Appreciation or depreciation occurs each year, independent of previous years. An effective measure to help investors make a decision for or against this investment is the maximum final return on the investment after 12 years in half of all cases: the median final value. To make their selection, small investors would have to calculate a probability distribution across the possible final investment values after 12 years based on the possible interest per annum. Even for this very simple scenario, this calculation would be extremely challenging—real investment decisions involve significantly more numerous and complex factors however.

The result of the calculation seems surprising: one sole 70-percent appreciation is nowhere near enough to offset a 60-percent depreciation. The price path therefore typically follows a downward trend. With an investment of 10,000 euros, in 50 percent of all cases, after 12 years, there is a maximum of just 989 euros of starting capital left, including interest. If the investors do not take the effects of compound interest into consideration but instead evaluate their investment according to the linearization rule of thumb, they would expect, in half of all cases, to receive a maximum of 16,000 euros on their investment after 12 years and would probably be very surprised at how little of the investment actually remains at the end. Failure to carry out the compound interest calculation could then explain the surprisingly risky behavior of many private investors in financial markets—for example, on the market for leveraged Exchange Traded Funds (ETFs) a significant proportion

is held by private investors.³ Recent warnings against these products issued by financial market regulatory authorities as well as the media indicated that private investors are unable to accurately assess the risks of investing in ETFs.⁴

The performance of ETFs tracks a pre-fixed index such as the US stock market index, the Dow Jones, or the German equivalent, the DAX30. While the performance of a simple ETF reflects that of the stock index on which it is based, the value of a leveraged ETF changes each day of the investment by a multiple of the percentage change in the value of the stock index. Thus, for example, a triple-leveraged ETF on the DAX30 will increase by three percent in one day, provided that the DAX30 gains one percent—should the DAX30 lose one percent of its value, however, the ETF would also fall by three percent. Such fluctuations in value are similar to those in the hypothetical pension scenario with regard to the compound interest effect.

If there are only minor fluctuations in the value of the ETF, applying the linearization rule of thumb to estimate returns on the investment for shorter periods would give a result that barely deviates from the correct solution. However, if the fluctuation margin is increased—by leveraging the ETF, for example—this makes it considerably more difficult to give an accurate estimate of the value of the investment. In short, the greater the fluctuations, the stronger the impact of failing to consider the effect of compound interest on the evaluation result and the more significant the potential miscalculation resulting from applying the linearization rule of thumb.

Apart from the fluctuations, the investment period also plays a decisive role. If the performance of an investment typically demonstrates a downward trend (as is the case with the hypothetical pension scenario), the median final value falls with each additional investment period. The majority of investments are made with the intention of them being liquidated at a fixed point in time in the relatively distant future. However, private investors usually only have access to annual or monthly information on investment returns to help them make their investment decision and compare different options. If the term of the investment is several decades, failure to understand the effect of compound interest may lead to a serious miscalculation of the investment risk. The lon-

³ S. Lan, C. Costandinides, S. Mercado, and B. Huang, US ETF Holder Demographics: Understanding ETF Usage (New York, Deutsche Bank: 2012).

⁴ Barron's, blogs.barrons.com/focusonfunds/2012/03/21/who-uses-leveraged-and-inverse-etfs-anyway/, blog entry by Brendan Conway, August 16, 2012 and see also „Beware of Leveraged ETFs," Wall Street Journal, May 11, 2012.

ger the investment time horizon, the stronger the compound interest effect—and hence also the more serious the miscalculation resulting from failure to observe the aforementioned effect.⁵

A Behavioral Experiment Shows That ...

One possible method for testing the effects of miscalculating compound interest is a behavioral experiment under fully controlled laboratory conditions. Compared to empirical analyses of investment decisions, this method has the advantage of enabling causal effects, i.e., the effects that are actually at the root of the decision, to be measured because in a laboratory environment all other effects that could also potentially influence investment decisions can be isolated and eliminated. Thus, a simple correlation, i.e., the possibility of two effects randomly occurring simultaneously, can almost certainly be ruled out. Experimental studies are therefore widely used in behavioral economics.

... Investors Ignore Compound Interest Effect, Unless They Are Reminded

Using an experimental study, DIW Berlin analyzed the impact of the investors' understanding of the compound interest calculation and of the fluctuation margin of the value of the given investment, as well as the effect of the investment horizon on their perception of the relevant investment risk. The experiment involved 128 students from the Technische Universität Berlin (TU) and a further 175 from University College London.⁶ The study examined participants' own perceptions of the median final values of different growth processes, irrespective of the students' individual risk propensity.

In an initial experiment, the TU Berlin participants were randomly divided into two groups. The testers then presented the participants in the control group (Group 1) with the hypothetical investment in the pension scenario. By questioning the participants about their investment decisions, it was possible to determine their individual perceptions of median final values for a 10,000-euro investment.

Participants in the study group (Group 2) received more information: although the testers described the investment opportunity in detail to participants in both groups, participants in Group 2 were also told how to calculate the possible final values after two periods by adding or deducting interest—and the impact this had on the probability distribution of the possible final values after 12 periods. Any differences in investment behavior between the two groups can therefore be explained by the discrepancy in their understanding of the compound interest calculation. At the end of the experiment, participants were remunerated according to their investment decisions.⁷

Since the participants were repeatedly asked about their investment decisions and received a computer-simulated final value for their investment after each new round, during the course of the experiment, they had the chance to realize that, in all probability, the investment was going to make a significant loss. In the first round, 98 percent of participants in the control group (Group 1) calculated median end values of over 2,000 euros; in the fifth and final round, despite the learning opportunity, this figure was still 86 percent. In the study group (Group 2), however, 70 percent of participants already came up with the correct median final value in the first round. It should be noted that the actual median final value was 989 euros. The fact that the control group significantly overestimated the median final value is consistent with the hypothesis that participants erroneously perceived a linear growth process.

... the Extent of the Miscalculation Increased with Value Fluctuations and Investment Maturity

An even more significant overestimate of the median final value if there is a higher value fluctuation margin and longer term of the investment product would provide further evidence of a linear growth process being erroneously perceived. An analogous experiment at University College London examined whether this was the case. In the experiment, all participants only received descriptions of the possible investments—with no reference to the issue of compound interest. Compared to the TU Berlin experiment, some parameters of the investment opportunity in the pension scenario were changed to make it possible to better examine the impact of changes in the value fluctuation margin and the time horizon. The fundamental principles of the investment remained unaffected, however. In addi-

⁵ For a more detailed mathematical elaboration of the effects of the use of the linearization heuristic, see L. Ensthaler, O. Nottmeyer, G. Weizsäcker, and C. Zankiewicz, „Hidden Skewness: On the Difficulty of Multiplicative Compounding Under Random Shocks,” DIW Berlin Discussion Paper 1337 (2013).

⁶ L. Ensthaler, O. Nottmeyer, G. Weizäcker, and C. Zankiewicz (2013), „Hidden Skewness: On the Difficulty of Multiplicative Compounding Under Random Shocks.”

⁷ The remuneration mechanism was designed so that each participant would receive a positive minimum sum in any event.

tion, for some of the participating students, ETFs now came into play: they were presented with either a simple or a triple-leveraged ETF on the DAX30 index. This method allowed the researchers to measure differences in the perception of such real financial products when there are different value fluctuation margins. In both cases (simple and triple-leveraged ETF), the time horizon was 2,000 trading days, i.e., approximately eight years. The participants were given a clear impression of the fluctuations in DAX30 index values during the period from 1964 to 2012.⁸ Thus, the testers provided a graphic illustration of, inter alia, the frequency distribution of the daily percentage value changes of the stock index over time. On the basis of this information, as in the first experiment, participants were able to make investment decisions which could be used to determine the individually perceived median final values of the respective ETF investment opportunity.

Finally, it was possible to compare the decisions of the various randomly assigned participants: in the case of the modified pension scenario, the group with the lower fluctuation margin and the group with the shorter time horizon were compared with the group with the higher fluctuation margin and the longer time horizon, respectively. In the ETF case, the testers only compared the groups with different fluctuation margins (simple and triple-leveraged ETFs).

In the case of the modified investment opportunity used in the pension scenario, both an increase in the fluctuation margin and an extension of the time horizon clearly resulted in a more significant overestimate of the median final value. In a comparison of a simple ETF with a triple-leveraged one for an eight-year investment period, while statistical analyses showed that there was no difference in the extent of the overestimate, at up to 70 percent, the proportion of participants overestimating the median final value was nonetheless very high in both ETF study groups (simple and triple-leveraged ETF). Based on these findings, it can be concluded that a misunderstanding of the compound interest effect can lead to a misconception about the investment risk not just in the laboratory but even for real existing financial products such as ETFs.⁹

⁸ Although the DAX30 has only been calculated since 1988, for this experiment, the index was calculated back to 1964 on a daily basis.

⁹ Additionally, the experiment retrieved information on further perception measures for the final value distribution for each investment opportunity. Both the range and the skewness of the given distributions were systematically underestimated by up to 100 percent of participants. These findings are also consistent with a linear perception of the performance of the given investment. For the relevant mathematical evidence, see L. Ensthaler, O. Nottmeyer, G. Weizsäcker, and C. Zankiewicz (2013), „Hidden Skewness: On the Difficulty of Multiplicative Compounding Under Random Shocks.

Box

Linearization Rule of Thumb

If private investors evaluate the performance of their investment according to the linearization rule of thumb, they would correctly capture the distribution of all possible random changes in value during the first period. However, for subsequent periods, the investors would consider the possible changes in value from the first period to be constant and would extend this distribution of absolute changes in value to the outstanding periods—and, in so doing, would be misunderstanding the economic growth process.

Formally, the following applies: γ_0 signifies the starting value of the investment (for example, 10,000 euros) and μ_t the random variable, which describes the relative changes in value over the periods t and has the same potential for realization in each period. The actual realizations of the random variables are independent of one another over the periods t . For period one, the following then applies:

$$\gamma_1 = \gamma_0 \mu_1$$

Here, a random variable is a variable whose value depends on coincidence. For the scenario of a hypothetical pension investment used in the present report, the μ_1 value would either be 1.7 (plus 70 percent in the case of positive interest) or 0.4 (minus 60 percent in the case of negative interest), with a 50-percent probability of occurrence in each case. Derived from this, the actual final value distribution of the hypothetical investment over the total number of T periods can be shown:

$$\gamma_T = \gamma_0 \prod_{t=1}^T \mu_t \quad (1)$$

Investors following the linearization rule of thumb now make the crucial error: they do not see the distribution of relative changes in value, as actually

Conclusion

It is difficult to understand economic growth processes without financial acumen. This is all the more significant since almost everyone is faced with an investment decision, when choosing a private pension, for example, at some point in their life. The experimental study conducted by DIW Berlin shows that private investors can

intended in (1), but instead perceive the absolute changes in value from the first period as remaining constant across all t periods. Therefore, the investors erroneously believe that the value of the hypothetical investment will increase by an absolute sum of 7,000 euros or will drop in value by an absolute sum of 6,000 euros in each period, with equal probability. It would, however, actually be correct to assume equally probable relative changes in value of plus 70 percent or minus 60 percent in each period (see figure).

The random variable for the perceived absolute change in value in period t is denoted by η_t . The investors erroneously believe that the range of possible values for this variable is constant and independent of one another over all the periods t .

Technically, the investors therefore erroneously perceive the final value distribution after T periods as

$$\gamma_T = \gamma_0 + \sum_{t=1}^T \eta_t \quad (2)$$

and see the distribution of η_t as corresponding to that of η_1 .

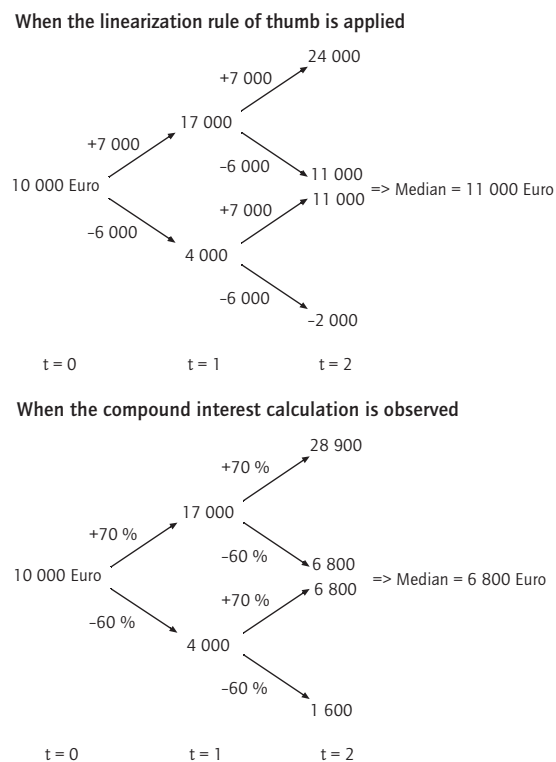
Applying the linearization rule of thumb as expressed in formula (2) therefore leads to the investors ignoring the compound interest effect, which, in turn, results in an overestimation of the median final value. As a result, with the aid of some less restrictive mathematical assumptions, it can be shown that applying the linearization rule of thumb, an increased margin of fluctuation, and a longer investment horizon lead to an even greater overestimation of the median final value.¹

¹ Further, it was also possible to demonstrate mathematically that both the range and the skewness of the final value distribution were systematically underestimated. For the relevant mathematical evidence,

Figure

Performance of Investment Over Two Periods

Sample calculation with starting capital of 10,000 euros



Source: diagram by DIW Berlin.

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When investors ignore the compound interest effect, they seriously overestimate the final value of their investment.

see L. Ensthaler, O. Nottmeyer, G. Weizsäcker, and C. Zankiewicz (2013), „Hidden Skewness: On the Difficulty of Multiplicative Compounding Under Random Shocks.

in fact seriously misunderstand economic growth processes. The principal findings are consistent with the hypothesis that, in making their investment decisions, investors carry out a linearized simplification of the calculation instead of the correct compound interest calculation—which can lead to a dramatic underestimate of the loss risk. A larger fluctuation margin of the val-

ue of the given investment or a longer investment horizon can reinforce this tendency.

The results of the laboratory experiment suggest that, in many cases, just a reminder of how compound interest works may be sufficient to help small private investors make a more realistic assessment of the investment risk—particularly if investment returns potentially fluctuate.

tuate significantly. Policy-makers should therefore regulate references to the compound interest effect to be listed in product information leaflets. Further, investment advisors might be obliged to make a specific reference to this effect in individual customer consultations. The provision of realistic final value calculations for different investment horizons might also provide the investor with more clarity.

The insights from the present study are also relevant when it comes to designing German school curricula: basic mathematical and statistical knowledge acquired in school could help individuals to better evaluate economic processes in later life. Students should learn, for example, what the properties of the median value of a distribution are and how the value is calculated. Exponential growth processes should also feature more prominently in classes—whether to help students make better investment decisions, correctly assess credit offers, or independently and critically evaluate macroeconomic growth processes such as inflation and economic growth later in life.

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