ChatGPT and Perception Biases in Investments: An Experimental Study[†]

Anastassia Fedyk
UC Berkeley

Ali Kakhbod
UC Berkeley

Peiyao Li
UC Berkeley

Ulrike Malmendier
UC Berkeley, NBER, and CEPR

Abstract

Does generative AI accurately capture demographic heterogeneity in investment preferences? We survey humans and GPT4 side-by-side and show that AI correctly predicts preferences by income, gender, and age (70% correlation). The overlap includes higher stock ratings among men and high earners. Human and AI-generated responses reflect similar reasoning: both refer to "risk" and "return" in general and, for stocks, to "knowledge" and "experiences." However, when not seeded with demographics, algorithmic bias emerges: AI responses predominantly mirror young, high-incomes males. Finally, AI generates more transitive rankings than humans. Our results highlight the promise of generative AI for applications such as robo-advising.

Keywords: Investment preferences, Large language models, Behavioral biases, Experimental economics, Financial surveys, Generative AI.
JEL Classification: C1, G10, G11, G12.

[†]First Draft: March 2024. Anastassia Fedyk, Ali Kakhbod, and Peiyao Li are with the Haas School of Business at UC Berkeley. Ulrike Malmendier is with the Department of Economics and the Haas School of Business at UC Berkeley, NBER, and CEPR. E-mails: Fedyk (fedyk@berkeley.edu), Kakhbod (akakhbod@berkeley.edu), Li (ojhfklsjhl@berkeley.edu), Malmendier (ulrike@berkeley.edu). We are grateful to Francesco D'Acunto, Amir Kermani, Dmitry Livdan, Alejandro Lopez-Lira, Alberto Rossi, Michael Reher, Gregor Schubert, and Stas Sokolinski for very helpful comments.

1 Introduction

The financial services industry is becoming increasingly automated, with robo-advising (automated investment advice) increasing more than tenfold in the past decade. This has broadly been considered a positive trend as it increases access to financial advice. Whereas traditional wealth management is often restricted to the richest customers, robo-advising has benefitted a wider range of investors by improving their diversification, reducing portfolio risk, and mitigating behavioral biases such as trend chasing and home bias (D'Acunto, Prabhala and Rossi, 2019; Reher and Sokolinski, 2024; Rossi and Utkus, 2021). Recent advances in artificial intelligence (AI), including large language models, have the potential to further transform and automate sectors such as the financial services industry (Abis and Veldkamp, 2024; Babina et al., 2024; Bybee, 2023; Cao et al., 2021; Lopez-Lira and Tang, 2023).

However, the effects of these developments are directionally ambiguous and potentially heterogeneous across investors. On the one hand, advances in AI can lead to efficiency gains and improved performance, as observed in financial statement audits (Fedyk et al., 2022) and sell-side analysts (Cao et al., 2021). On the other hand, AI models have suffered from "algorithmic bias"—the tendency to perform better for some demographic groups than others—in multiple areas including medicine (Kadambi, 2021; Zou and Schiebinger, 2018) and image recognition (Buolamwini and Gebru, 2018). Concerns about algorithmic bias are especially relevant in the financial domain, where investors display a large gender imbalance (Barber and Odean, 2001). To date, the introduction of machine learning has been found to disproportionately benefit white borrowers in credit screening applications (Bartlett et al., 2022; Fuster et al., 2022), and existing robo-advising tools show uneven gains across age groups (Reher and Sokolinski, 2024). If AI models are trained on imbalanced groups—for example, young men posting on platforms such as StockTwits and Seeking Alpha—then these models may fail to accurately reflect the investment preferences of other demographic groups.

In this paper, we directly assess the extent to which a state-of-the-art generative AI model can match differences in investment preferences across three key demographic characteristics shown to predict stock-market participation in the prior literature (e.g. Agnew, Balduzzi and Sunden, 2003; Hong, Kubik and Stein, 2004): income, gender, and age. To do so, we first run a real-world custom survey eliciting the investment preferences of a representative sample of 1,272 participants. The survey was run in two waves: October 2023 and March 2024. It consists of three components: (i) we ask for categorical ratings of three investment options—stocks, bonds, and cash—-on a scale from "very negative" (encoded as 1) to "very positive" (encoded as 5); (ii) we ask for a free-form written explanation of each rating; and (iii) we ask participants to compare each pair of investment options (stocks vs. bonds, stocks vs. cash, and bonds vs. cash) by choosing either the first option, the second option, or "indifferent."

We query OpenAI's GPT4 model using the same survey questions and demographics, with 1,200 simulated runs. That is, we seed the prompts with different demographic characteristics and describe the type of questions and permitted answers (rating versus free-form). We then ask the exact same questions as in the human survey. The respondents of the human survey (and the simulated GPT4 agents) are balanced across the key demographics, with 49.8% (50%) identifying as male, a median age of 37 (39), and a median personal income of $53,000 ($55,000). We also run an additional query (150 simulated runs) that does *not* include demographic information.

We compare the human survey responses and the GPT4-generated responses along three dimensions. First, we analyze the ratings each human respondent (or simulated GPT4 agent) assigns to each investment option, examining how the human ratings vary across demographics and the extent to which these patterns are captured by the GPT4-generated responses. Here, we also contrast the baseline results with the results when prompts are not seeded with demographic information. Second, we take a deeper look at the reasonings (free-form explanations) behind the ratings to study whether GPT4 is

able to capture the main themes in the justifications that human participants provide for their investment choices. Third, we discuss one difference of generative AI in modeling investment preferences: GPT4 responses almost always have transitive preference orderings, whereas human responses are prone to violations of transitivity when expressing indifference. This difference showcases an advantage of using AI-enhanced investment advice if violations of transitivity constitute a cognitive mistake that humans make but would prefer to avoid.

For the first step, the comparison of investment ratings by human participants versus GPT4, we form eight demographic groups categorized by gender (men or women), age (above or below the median), and income (above or below the median). For example, if a male participant has above-median income and is at least as old as the median age, we categorize him as an older, high-income (wealthy) man. We construct two vectors, one for human survey participants' ratings and one for GPT4-generated ratings. Each vector consists of 24 average numerical ratings: one from each of the eight demographic groups for each of the three investment options. These two vectors show very high correlations: Pearson correlation of 0.73, Spearman correlation of 0.70, and Kendall correlation of 0.57, all significant at the 1% level. We then repeat the analysis separately for each investment option, with vectors of eight average ratings across the eight demographic groups. This analysis also shows positive and significant correlations between human survey responses and GPT4-generated responses. For bonds, the Pearson correlation is significant at the 1% level, while Spearman and Kendall correlations are significant at the 5% and 10% levels, respectively. For stocks and cash, all correlation types range between 0.65 and 0.81 and exhibit statistical significance at the 1% level. Thus, there is a robust positive correlation between the averages of GPT4-generated ratings and human ratings, indicating the reliability of GPT4 in evaluating investment options across demographic groups.

Looking specifically at the differences in the ratings across demographic groups, we confirm that male human participants rank stocks higher than female participants, and

the reverse for bonds, consistent with prior evidence (Agnew, Balduzzi and Sunden, 2003). Higher-income individuals rate stocks and bonds higher and rank cash lower than lower-income individuals (Hong, Kubik and Stein, 2004). Finally, older individuals rate cash higher than younger individuals. Almost all of these patterns are correctly captured by GPT4-generated responses, which predict higher stock ratings for men, higher stock and bond ratings for higher-income individuals, lower cash ratings for higher-income individuals, and higher cash ratings for older individuals. Overall, GPT4 aptly reflects common demographic differences in preferences across investment options.

We also show, however, that this result hinges on the ability to instruct GPT4 to assume specific demographic identifies. In the sample of 150 queries where we elicit investment preferences from GPT4 *without* specifying demogpraphic characteristics, the responses overwhelmingly (in 55% of all cases) resemble young, high-income men (a demopgrahic group that comprises less than 15% of the population). Thus, querying large language models with representative demographic specifications is pivotal to avoiding algorithmic bias.

To examine the real economic impact of these results, we supplement our analysis of investment preferences with an analysis of actual asset allocations. Specifically, we leverage the asset allocation data from the 2022 Survey of Consumer Finances to estimate demographic differences in allocations to stocks, bonds, and cash, and the extent to which they are captured by GPT4. We find strong agreement between significant demographic patterns in the SCF data and GPT4-generated allocations: GPT4 correctly reflects the differential allocations across gender (women leave a higher proportion of their assets in cash holdings), age (older individuals allocate more of their total holdings to bonds), and income (high-income individuals allocate more of their holdings to stocks and leave a lower proportion of their assets in cash).

Next, we understand the reasons behind the investment ratings by drawing insights from the free-form *text* explanations accompanying each rating. First, we observe that

risk and return are the two most prevalent themes in both human and GPT4-generated responses. To quantify a respondent's perception of each investment option along risk and return dimensions, we construct two numerical axes representing an asset's perceived risk and return using a textual embedding technique called Semantic Axis (An, Kwak and Ahn, 2018). The orderings of stocks, bonds, and cash from the GPT4-generated responses and human survey responses are consistent along both dimensions: stocks are deemed to have the highest return, followed by bonds, then cash; and stocks are deemed to have the highest risk, followed by cash, then bonds.

Furthermore, the mappings between the risk and return representations of the free-form explanations and the associated numerical ratings are very similar between human participants and GPT4-generated responses. A one-standard-deviation increase in the return dimension corresponds to a 0.79-standard-deviation increase in the human ratings, with the same relationship for GPT4 responses. In the risk space, a one-standard-deviation increase in the human participants' risk perception translates into a 0.56-standard-deviation lower rating, and the effect size is only slightly larger (by 0.05) for GPT4-generated responses. Overall, the relationship between risk and return encodings and categorical ratings of investment options is very similar across actual survey responses and simulated GPT4 responses.

We further develop the analysis of free-form explanations by identifying auxiliary themes impacting stock-market participation. Low stock-market participation is an enduring concern, especially among female, older, and lower-income individuals (Guiso, Sapienza and Zingales, 2008; Hong, Kubik and Stein, 2004; Van Rooij, Lusardi and Alessie, 2011). We use generative AI's summarization capabilities to extract the main themes (other than risk and return) differentiating explanations for high versus low ratings of stocks, separately for human survey responses and GPT4-generated responses. The two main themes emerging from the summarization exercise are (i) knowledge and understanding of the stock market, and (ii) personal experiences with investing in the stock

market (and resulting emotional responses). Prior literature has shown that financial literacy is a major driver of stock market participation (Van Rooij, Lusardi and Alessie, 2011) and that personal experiences shape attitudes to inflation and risk-taking (Malmendier and Nagel, 2011, 2016). Our comprehensive textual analysis of survey responses confirms that these two themes are key drivers in attitudes toward the stock market.

We document that generative AI matches human responses along both the knowledge and the experience dimension. For example, 23% of human participants' explanations reflect negative experiences with the stock market, compared to 24% of GPT4-generated explanations. The demographic differences also match. Men and higher-income individuals are more likely to exress familiarity with the stock market. Younger individuals, men, and higher-income earners discuss more positive stock-market experiences. Thus, generative AI correctly captures the directionality of the "reasoning" behind attitudes toward the stock market across multiple dimensions, from the canonical risk and return considerations to more subjective experiential aspects such as knowledge and personal experience.

Moreover, when we examine the correlations between the four key themes in the free-form explanations of stock ratings—risk, return, knowledge, and experience—we find very similar patterns human survey responses and GPT4-generated responses. Both knowledge and past experiences correlate positively with return perceptions and negatively with risk perceptions, and knowledge and experience are positively correlated with each other. This means that GPT4 correctly reflects the full structure of reasoning: how each theme translates into categorical ratings, how the perceptions vary across demographics, and how the themes relate to each other.

Finally, we identify a potential advantage of using generative AI to simulate survey responses: GPT4-generated responses are almost always transitive, whereas human survey responses are less so. To examine transitivity within preference orderings, we focus on relative-comparison responses where participants directly rank pairs of investment

options. GPT4-generated preference orderings are transitive 98.7% of the time, compared to 84.4% of human preference orderings. We further explore the sources of intransitivity within the human dataset. First, we observe that male human participants have transitive preference orderings significantly more often than female participants. Second, when human survey participants have a strict preference over each pair of options, almost all of them exhibit transitive preferences. However, when at least one "indifferent" response is present, only 72% of participants maintain transitivity. Combining these two observations, we observe that a larger percentage of female participants report at least one "indifferent" response, and women with "indifferent" responses violate transitivity more often than men. We find that most of the discrepancy in transitivity between human survey participants and simulated GPT4 agents can be explained by these two factors—gender and indifference.

Our results contribute to the rapidly growing body of work on the effect of financial technology on the investing landscape. The availability of low-commission online trading platforms such as Robinhood has expanded retail investor participation in the stock market, while the rise of robo-advising has increased the prevalence of automated investing (Barber et al., 2022; D'Acunto, Prabhala and Rossi, 2019; Welch, 2022). These trends underscore the importance of understanding how technological advances will affect an investing landscape comprised of increasingly diverse participants. To date, robo-advising has led to greater diversification (D'Acunto, Prabhala and Rossi, 2019), returns (Reher and Sokolinski, 2024), and bias mitigation (D'Acunto, Ghosh and Rossi, 2022) in portfolios. However, the directional effects in terms of both portfolio changes and welfare gains have been unevenly distributed across demographics such as investor age (Reher and Sokolinski, 2024; Rossi and Utkus, 2021). Coupled with the recent evidence of algorithmic bias in domains ranging from medicine (Kadambi, 2021) to credit supply and loan interest rates (Bartlett et al., 2022; Fuster et al., 2022), this raises the concern that new advances in machine learning—such as the use of large language models trained on text

from the Internet—may disproportionately reflect the investment preferences of specific demographic groups (e.g., young men). Our results assuage those concerns, showing that in the domain of investing, large language models such as OpenAI's GPT4 correctly reflect directional differences in investing preferences across demographic characteristics (gender, age, and income) both in investment ratings and in the free-form explanations behind those ratings.

In doing so, we also contribute to the emerging literature on the effects of AI on various sectors of the economy, with our work speaking to the financial services sector in particular.[1] The introduction of generative AI (proxied by GPT4) and its effects on the labor market and firm performance have been studied by Bertomeu et al. (2023); Brynjolfsson, Li and Raymond (2023); Eisfeldt et al. (2023); Eloundou et al. (2023); and Noy and Zhang (2023). The extant evidence on the effects of GPT technology, particularly in finance, presents a mixed picture. On the one hand, Li, Tu and Zhou (2023) find that generative AI is positively biased in forecasting earnings and has larger forecast errors than sell-side analyst consensus forecasts. On the other hand, Lopez-Lira and Tang (2023) show that generative AI has predictive power for future stock market returns based on news headlines, Hansen and Kazinnik (2023) find that AI is able to classify policy stances of Federal Open Market Committee announcements, and Bybee (2023) showcases the potential of generative AI to generate economic expectations from news, with generated expectations matching survey expectations and displaying similar biases.[2]

We contribute to this literature by examining generative AI's ability to capture individual-level heterogeneity in investment preferences. We document that generative AI reflects similar demographic patterns to human surveys in both elicited investment preferences and accompanying explanations while providing more transitive orderings. This similarity extends to asset allocation, where GPT4 correctly captures heterogeneity across

[1] Veldkamp (2023) and Abis and Veldkamp (2024) spotlight the critical role of data and big data technologies in the modern economy, noting a shift away from labor-intensive processes.

[2] Outside finance, Horton (2023) shows that generative AI behaves similarly to human participants, with analogous biases and responsiveness to endowments.

different demographic groups. Overall, our results signal promise for the application of generative AI in areas such as robo-advising. We also offer a methodological contibution by introducing a flexible, low-cost approach to extracting meaningful information from abstract text embeddings in data such as free-form explanations. This approach allows researchers to evaluate text documents along a flexible set of labeled axes beyond commonly considered linguistic attributes such as sentiment, novelty, and complexity (Fedyk and Hodson, 2023; Loughran and McDonald, 2014; Tetlock, 2007).

The remainder of the paper proceeds as follows. We describe the data collection procedures for both the human investment survey and the GPT4 prompts in Section 2. We present the main analysis of the consistency between investment ratings in the human survey and GPT4-generated responses in Section 3 and then analyze rating explanations in Section 4. Section 5 examines the transitivity of human survey participants' preference orderings and GPT4-generated responses, and Section 6 concludes.

2 Data Collection: Human and GPT4 Investment Preferences

We describe the methodology for collecting human investment preferences across demographics and analogous GPT4-generated responses for our benchmarking exercise.

2.1 Human survey

Human responses come from a survey of a representative sample of 1,272 individuals recruited through the Prolific platform. The survey was conducted in October 2023 and March 2024.[3] 1,264 individuals completed the entirety of the survey, including the demographic questionnaire at the end. The sample of respondents is balanced on age, gender,

[3] An identical survey was administered on both dates. An initial sample of 469 individuals was recruited in October 2023, and the survey was scaled with an additional 803 participants in March 2024.

and income. Specifically, 49.8% of the respondents reported being male, 47.5% identified as female, 2.3% chose “Other" gender, and 0.5% declined to say. The median age of the respondents is 37, and the average is 39.7, comparable to the median age of the US population, which the US Census reports as 38.9 for 2022. The median income is $53,000 (with an average of $68,876), very close to the $54,339 median earnings for full-time year-round civilian employees in the US Census for 2021. Compensation for participating in the survey averaged $15.45/hour.

The survey asked the respondents to rank three investment options—stocks, bonds, and cash—separately and relative to each other. The first three questions were single-rating questions, asking the respondents to rank each investment option on a scale of "very negative" (encoded as 1), "somewhat negative" (encoded as 2), "neutral" (encoded as 3), "somewhat positive" (encoded as 4), and "very positive" (encoded as 5). The three single-rating questions were presented in random order to avoid anchoring effects. Each of the three single-rating questions was followed by a free-form text entry question asking why the respondent chose that rating, which required responses with a minimum length of 20 characters. Panel A of Figure B1 in the Online Appendix displays an example single-rating question.

Next, the respondents faced three relative-comparison questions: whether they prefer stocks or bonds, stocks or cash, and bonds or cash. Each of these questions had three choices (corresponding to the two assets being compared and an option for indifference) and were accompanied by free-form text entry “why?" questions requiring responses with a minimum of 20 characters. The order of the relative-comparison questions was randomized across participants. Furthermore, the order of the options *within* each question was also randomized across participants (e.g., half of the participants were asked whether they prefer "stocks or bonds," and the other half were asked whether they prefer "bonds or stocks") to avoid biasing the participants towards any options on aggregate. Panel B of Figure B2 in the Online Appendix shows an example relative-comparison question. The

exact instructions used in the survey are included in Online Appendix B.1.

We performed the following cleaning steps on the survey data before commencing the analysis. First, we removed outliers in age and income using an inter-quantile range (IQR)-based rule. Specifically, a data point is considered an outlier if the participant's age or income is at least 1.5 IQRs above or below the median. Additionally, we excluded human responses where the participant refused to disclose their gender or identified as non-binary because we lacked sufficient data in the non-binary category to perform meaningful inference (accounting for less than 3% of the sample). After these cleaning procedures, we retain a sample of 1,074 individuals with an average (median) age of 38 (36) and an average (median) income of $\$53,000$ ($\$50,000$) rounded to the nearest 1,000 dollars.

2.2 GPT4 data collection

We simulate survey data collection using GPT4 to conduct a cleanly identified comparison with human survey data. As in the human survey, we elicit responses to three types of questions:

1. How do simulated GPT4 agents rank each investment option (stocks, bonds, cash)?
2. What is the stated reasoning for the ratings (free-form responses)?
3. What is the preference ordering of the GPT4 agent among the three options (pairwise comparisons)?

For the first type of question, we give each simulated GPT4 agent five choices, analogous to the human survey: very positive, somewhat positive, neutral, somewhat negative, and very negative. We convert these multiple choice ratings to numerical ratings from 1 (very negative) to 5 (very positive). For the second type of question, we ask for a short explanation of each rating response using 5 to 10 words. For the third type of question (comparisons), we offer three choices: option 1, option 2, and indifferent. For example, when

comparing stocks and bonds, the options are preferring “Stocks," preferring “Bonds," and “Indifferent." Additionally, we ask each GPT4 agent to report the gender, age, and income of its imagined identity. Online Appendix B.2 presents a sample prompt.

We query GPT4 1,200 times, seeding it with different demographic characteristics.[4] We specify the median age and income according to the United States census data discussed in Section 2.1, querying GPT4 responses for imagined male or female agents above or below the median in age and income. GPT4 can follow this instruction 100% of the time. Therefore, we have an even split of the data across the 8 demographic groups: males of below-median age and at most median income, males of at least median age and at most median income, etc. The male-to-female ratio of the reported gender (GPT4 agents) is 50-50, the average (median) age is 37 (39) years old, and the average (median) personal income is $\$56,000$ ($\$55,000$) rounded to the nearest 1,000 dollars. We use the same outlier detection procedure to remove outliers as we applied to the human survey results. After processing, we retain responses from 1,042 simulated GPT4 agents with an average (median) age of 36 (36) years old and an average (median) income of $\$53,000$ ($\$53,000$) rounded to the nearest 1,000 dollars.

3 Investment preferences across demographics

The first question we address is “how similar are GPT4-generated ratings of investment options to human ratings?” Our primary analysis compares the survey responses from our representative sample of human participants against GPT4-generated responses. We supplement the survey analysis with a comparison of actual asset allocations using the Survey of Consumer Finances, which yields very similar results.

[4]Our goal is for GPT4 to simulate a pool of participants in each demographic group; therefore, we set the temperature for GPT4 as 0.8 to allow for a moderate amount of variation in its responses.

3.1 Asset ratings in the survey responses

In the survey, we observe the ratings of stocks, bonds, and cash across eight demographic groups: males with below median age and at most median income, males with at least median age and at most median income, males with below median age and above median income, males with at least median age and above median income, females with below median age and at most median income, females with at least median age and at most median income, females with below median age and above median income, and females with at least median age and above median income.

On aggregate, both human and GPT4 responses rate stocks the highest, followed by bonds, and then by cash. The average human survey ratings are 3.8 for stocks, 3.6 for bonds, and 3.1 for cash. The average GPT4 ratings are 3.7 for stocks, 3.7 for bonds, and 3.2 for cash. There is some heterogeneity between the ratings of different demographic groups, consistent with the literature on demographic predictors of stock market participation. For example, in the human survey, women rate stocks as 3.6 on average, while men rate them as 3.9. Critically, similar differences are reflected in the GPT4 responses, which accurately capture preference heterogeneity across demographics.

To assess the similarity between human and GPT4 ratings, we start by computing 24 average numerical ratings from each set of responses (human survey and GPT4): one average rating from each of the eight demographic groups on each of the three investment options. We compute the correlations between the human and GPT4-generated ratings across these 24 groups. Table 1 shows the corresponding Pearson, Spearman, and Kendall correlations in the top row.[5] The demographic patterns in the ratings from human survey participants and GPT4 are highly consistent, with a Pearson correlation of 0.73, Spearman correlation of 0.70, and Kendall correlation of 0.57. To compute the statistical significance of these correlation coefficients, we use a bootstrap of 10,000 samples drawn randomly with replacement from the human survey and GPT4 datasets, respec-

[5]For a detailed definition of each of the correlation coefficients, refer to Online Appendix Section E.4.

tively. Each bootstrap has the same size as the original data. The bootstrapped standard errors are reported in parentheses in Table 1. All three correlation coefficients are highly statistically significant at the 1% level.

We also conduct a similar analysis separately within each asset class, focusing on the eight average ratings (across demographic groups) for stocks, bonds, and cash. These correlations are also very high. For stocks, the differential ratings across demographic groups from responses generated by humans and GPT4 show a Pearson correlation of 0.78, a Spearman correlation of 0.81, and a Kendall correlation of 0.71. All three correlations are significant at the 1% level. Similarly, the human and GPT4 ratings for cash show a Pearson correlation of 0.77, Spearman correlation of 0.64, and Kendall correlation of 0.64 across the eight demographic groups, all significant at the 1% level. The correlations for bonds are lower but still statistically significant, with a Pearson correlation of 0.58 (significant at the 1% level), Spearman correlation of 0.45 (significant at the 5% level), and Kendall correlation of 0.27 (significant at the 10% level).

	Pearson	**Spearman**	**Kendall**
All	0.728^{***}	0.695^{***}	0.565^{***}
	(0.042)	(0.053)	(0.046)
Stocks	0.783^{***}	0.810^{***}	0.714^{***}
	(0.099)	(0.125)	(0.132)
Bonds	0.581^{***}	0.452^{**}	0.286^{*}
	(0.178)	(0.210)	(0.170)
Cash	0.768^{***}	0.786^{***}	0.643^{***}
	(0.152)	(0.167)	(0.161)

TABLE 1: This table reports the Pearson, Spearman, and Kendall correlations between GPT4-generated responses and human survey responses. These correlations are computed based on the average rating from each demographic group for the three investment options (pooled and separately). Bootstrapped standard errors are reported in parentheses.

Overall, these results show that GPT4-generated ratings of stocks, bonds, and cash across different demographic groups are highly correlated with the actual heterogeneity of human ratings across demographic groups. This correlation is robust to using continuous values (Pearson correlation) and rank orderings (Spearman and Kendall correlations).

To examine the exact demographic patterns reflected in human and GPT4-generated data, we estimate regressions where the dependent variable is the rating (separately for stocks, bonds, and cash), and the independent variables are the demographic characteristics: gender, age, and income. We estimate the regression for human and GPT4-generated data separately to assess the extent to which the coefficients agree. In particular, we focus on coefficients that are statistically significant in both human and GPT4 responses and compare the direction of the effects.

Table 2 shows the results: five out of the six significant coefficients are significant in the *same* direction in both human and GPT-4 data. Specifically, older respondents tend to rate cash more highly than younger ones, women tend to rate stocks lower than men, higher-income individuals rate both stocks and bonds higher than lower-income individuals, and higher-income individuals rate cash less favorably than lower-income individuals. The only aspect on which GPT4 responses fail to correctly capture demographic differences in human investment preferences is the relationship between gender and bond ratings: GPT4 expects women to rate bonds higher than men, whereas male human survey participants place higher ratings on bonds than women. This one-off difference may be attributed to GPT4 reflecting the standard investment allocation tradeoff between stocks and bonds, where men's higher allocation to stocks comes at the expense of bonds (Agnew, Balduzzi and Sunden, 2003).

Overall, Tables 1 and 2 show that GPT4 responses are highly correlated with human surveys, correctly reflecting that women and older investors have lower preferences for stocks than men and younger investors, and that income is a major driver of investment preferences, with higher-income individuals favoring stocks and bonds and being less attracted to cash.[6]

[6]This alignment between GPT4 agents' and humans' heterogeneous patterns across demographics is robust when we use subsample bootstrapping to compute the confidence intervals of the coefficients. In this case, we find that higher-income individuals rate stocks and bonds higher than their counterparts, and males rate stocks higher than females. GPT4 and human responses are directionally aligned in all four coefficients.

	Human direction	GPT4 direction	Agreement
old: cash	+	+	✓
female: stocks	-	-	✓
female: bonds	-	+	×
high-income: stocks	+	+	✓
high-income: bonds	+	+	✓
high-income: cash	-	-	✓

TABLE 2: This table displays the relationship between ratings of the investment options (stocks, bonds, and cash) and demographic characteristics (age, gender, and income). We present the six correlations that are significant in data generated by both human participants and GPT4. A plus sign in the second and third columns means that the corresponding demographic is positively correlated with the rated asset. For example, the first row of this table shows that older individuals and simulated GPT4 agents both prefer holding cash more than their younger counterparts.

3.2 Asset allocation

In this subsection, we investigate whether the similarity in survey responses between human participants and GPT4 translates into similar asset allocation patterns. To do so, we leverage real household-level asset allocation data from the 2022 Survey of Consumer Finances (SCF) (Reher and Sokolinski, 2024).

The SCF is a comprehensive triennial survey conducted by the Federal Reserve Board in cooperation with the U.S. Department of the Treasury. It collects detailed information on the financial characteristics of U.S. households, including data on income, net worth, balance sheet components, pension plans, and other financial behaviors. We observe the age, gender, and income of each respondent. The SCF dataset is at the household level, which can include multiple income earners (e.g., married couples). In our main specification, we restrict the sample to single-person households; however, the results remain the same if we include all households (with demographics marked by the head of household) and use fixed effects for the number of people in each household. For the asset allocation, we observe the amount of money in their savings and checking accounts (cash), the amount invested in publicly traded stocks, and the amount invested in bonds. We compute the fraction of allocation in each of these three asset classes as a share of the total.

We generate analogous asset allocations from GPT4 using the prompt presented in Online Appendix C—specifying the age, gender, and income of a participant and asking for an allocation across the three asset classes adding up to 100%.

We analyze the demographic differences in allocations, and whether these align between actual human data (the SCF) and responses generated by GPT4. The significant differences in asset allocation across demographic groups are shown in Table 3, analogous to the demographic differences in preferences reported in Table 2. Older individuals invest more in stocks and bonds, females keep a larger proportion of their assets in cash, and high-income earners invest more in stocks and keep less cash. These patterns are mirrored in the responses generated by GPT4. Overall, large language models are able to match not only demographic differences in self-reported preferences across asset classes but also how those differences translate to actual asset allocation. This evidence further highlights the potential of large language models for querying heterogeneous investment preferences in applications such as robo-advising.

	Human direction	**GPT4 direction**	**Agreement**
old: stocks	+	+	✓
old: bonds	+	+	✓
female: cash	+	+	✓
high-income: stocks	+	+	✓
high-income: cash	-	-	✓

TABLE 3: This table displays the relationship between the portfolio allocation to each asset and demographic characteristics (age, gender, and income). We show the five correlations that are significant in both human response data and the GPT4o-generated data. A plus sign in the second and third columns means that the corresponding demographic is positively associated with the allocation to the corresponding asset.

3.3 Robustness and Additional Analysis

We examine the robustness of our main result to several variations in the large language model. First, we show that the results are the same between the standard GPT4 model and the newer GPT4o model. Second, we demonstrate that the results are robust to variations in the AI prompt design, specifically considering a practical extension of the prompt: providing the model with access to a small sample of real human survey data. Finally, in Subsection 3.3.3, we present an additional analysis showing that *without* specifying demographics of simulated GPT4 agents, the responses do display some algorithmic bias: specifically, they tend to over-represent young, wealthy men.

3.3.1 Robustness to model choice: generating responses with GPT4o

We show the robustness of our main result to the choice of large language model by replicating the same analysis with a newer state-of-the-art model—GPT4o (released in May 2024).

We use the same prompts as the main analysis and collect the same sample size in each demographic group (150 responses). Tables D1 and D2 in the Online Appendix show that the newer model performs even better than our baseline results: GPT4o responses are more highly correlated with human survey responses (compared to GPT4), and the rating patterns across demographic groups are more similar. More details on this analysis can be found in Online Appendix D.1. These results demonstrate that our key finding is not restricted to one GPT model, and the alignment between large language models and human surveys is likely to increase as newer, more advanced models are released.

3.3.2 Prompt variation: low-cost few-shot learning

We explore the robustness of our results to varying the input to the large language model by considering an important application. Although running large human surveys can be costly and time-consuming, sometimes researchers have access to a small pilot sample

containing some real survey data, which may be too small to draw statistically significant inferences. However, we show in this section that by incorporating this small dataset into the large language model through a low-cost "fine-tuning" approach called few-shot learning, we can further improve the alignment between the responses generated by GPT4 and real humans.

We begin with a small random sample of 100 respondents from the human survey data (under 10% of the entire sample). We then embed a random set of three of these samples from the same demographic group (age, gender, and income) into each prompt when querying GPT4. Online Appendix D.2 presents the full prompt and a more detailed discussion of the process. We then collect the GPT4-generated responses like before, using 150 samples from each demographic group. We compare these GPT4-generated responses to the *remaining* responses from the human survey (i.e., those that were not used as the 100 "pilot" sample). As shown in Tables D3 and D4 in the Online Appendix, the alignment between the few-shot learning results and real human responses is even higher than in our baseline analysis: correlations between demographic group averages reach 80%, and there is directional alignment on all seven significant relationships between demographics and ratings. Therefore, if researchers have access to a small pilot dataset of real human responses, it is beneficial to include this information via few-shot learning when using GPT4 to generate synthetic survey responses.[7]

3.3.3 GPT4 agents' default behavior

In this subsection, we explore GPT4's default behavior when no demographic information is provided in the prompt. Our baseline prompt shown in Online Appendix B.2 begins by describing the demographic group of each GPT4 agent (e.g., *"Imagine you are a male online survey participant who is below 39 years old and above 18 years old with an annual*

[7]The pilot sample of 150 responses alone has low statistical power and uncovers only two significant correlations—that old individuals rate cash higher than young individuals and high-income earners rate stocks higher than low-income earners. Leveraging GPT4 helps overcome the low-power issues of small datasets like this sample, uncovering the full set of significant correlations in the data.

income above 54 thousand"), then explains the task and the format of the responses, and finally poses the survey questions. We now try using the prompt shown in Online Appendix D.3, which removes the first part (defining the demographic group). We collect 150 responses with this prompt and study the default responses along two dimensions. First, we directly examine the self-reported demographics of each agent; then, we compare the rating patterns of these responses to the responses of different human groups.

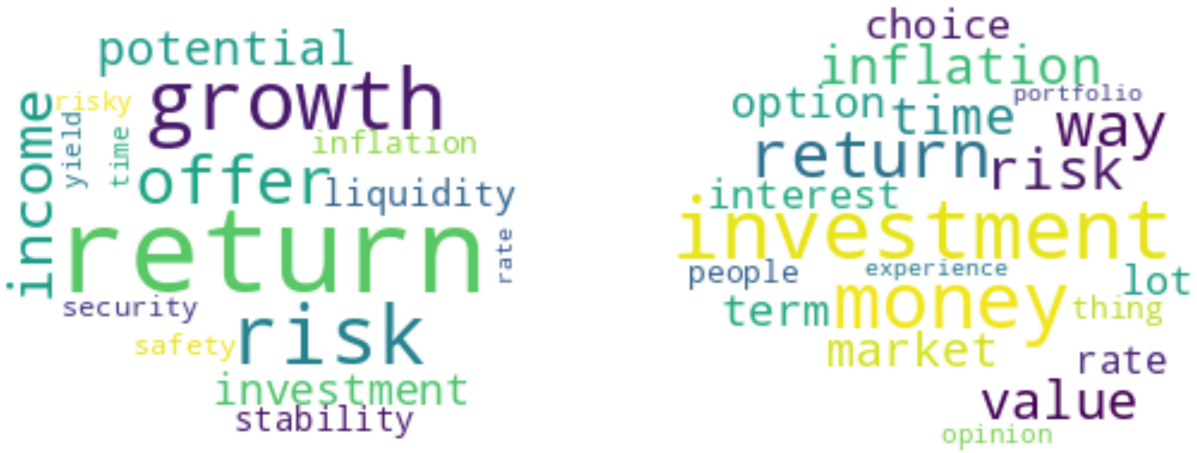
The self-reported demographics of unrestricted GPT4 responses are balanced on gender (56% female) but tend to be wealthy (all of the responses report annual income exceeding $54,000 annual income) and young (only 9 out of 150 agents are at least 39 years old). When we look at the ratings of investment options, most of the demographically unconstrained responses generated by GPT4 map to the young and high-income groups (and largely male): 28% of GPT4 agents are closest to the young, high-income, female group, and 54.667% of GPT4 agents are closest to the young, high-income, male group.[8] Thus, when we query large language models *without* specifying demographic characteristics, algorithmic bias becomes a concern. The unrestricted responses overwhelmingly overrepresent the dominant group, which in the case of investing comprises young and high-income men.

4 Understanding explanations of ratings

In Section 3, we have shown that the categorical investment ratings generated by GPT4 are closely aligned with human survey ratings across different demographic groups. We now take advantage of the free-form justifications (the "why?" questions accompanying the ratings) to examine the extent to which large language models match the *reasoning* provided by human participants.

[8] More details about the prompt we use and the detailed results can be found in Online Appendix D.3.

4.1 Most common themes



(a) GPT4 word cloud

(b) Human word cloud

Figure 1: Word clouds of GPT4 and human responses constructed based on the frequency of words in the free-form explanations. We only show words that are used as nouns in the explanation because we are interested in detecting the major themes.

We begin by conducting a simple word count of all nouns that appeared in human and GPT4 responses, separately, to determine the most frequent themes being discussed. Table A1 in the Online Appendix shows the 15 most common nouns in the responses from the human survey (on the left) and the 15 most common nouns in the GPT4-generated responses (on the right). The human responses use more varied language than those generated by GPT4 (the most common term in GPT4-generated responses—"return"—appears 1,408 times, compared to a third of that for the most common terms in human responses). However, the most common themes in both sets of responses are similar, focusing on investments, risk, and return. Figure 1 offers a graphical illustration of the most common terms using word clouds. There are differences in the terms used—human responses focus on "investment" and "money," whereas GPT4 generates more discussion of "return" and "growth," but the general patterns are similar: both sets of explanations concentrate on financial tradeoffs and rewards.

4.2 Discussions of risk and returns in human and GPT4 explanations

Motivated by the main themes emerging from the most frequent terms, we conduct a more rigorous examination of the two main themes in the responses, which correspond to the two principal dimensions of utility functions studied in financial economics: risk and return. First, we construct these two semantic dimensions using embeddings.[9] We begin with the embeddings of four principal sentences:

- Return
    1. "This asset has very high return."
    2. "This asset has very low return."
- Risk
    1. "This asset has very high risk."
    2. "This asset has very low risk."

We denote these four embeddings as $\mathbf{V}^h_{\text{ret}}$, $\mathbf{V}^l_{\text{ret}}$, $\mathbf{V}^h_{\text{risk}}$, and $\mathbf{V}^l_{\text{risk}}$ (normalized to have unit length), respectively. Embeddings are numerical representations of text, and the only conceptual difference between $\mathbf{V}^h_{\text{ret}}$ and $\mathbf{V}^l_{\text{ret}}$ is in the return dimension: high versus low. Therefore, as shown in Figure 2, by taking the difference between the vectors $\mathbf{V}^h_{\text{ret}}$ and $\mathbf{V}^l_{\text{ret}}$, we can obtain a vector axis pointing from low to high returns:

$$\mathbf{V}_{\text{ret}} = \mathbf{V}^h_{\text{ret}} - \mathbf{V}^l_{\text{ret}}. \tag{1}$$

[9] This approach builds on the idea of Semantic Axis (SemAxis) in the natural language processing literature, which uses differences in embeddings of words in opposite semantic classes (e.g., happy vs. sad) to build a numerical scale of a meaning (An, Kwak and Ahn, 2018).

Similarly, we can obtain a vector axis pointing from low to high risk by differencing $\mathbf{V}^h_{\text{risk}}$ and $\mathbf{V}^l_{\text{risk}}$:

$$\mathbf{V}_{\text{risk}} = \mathbf{V}^h_{\text{risk}} - \mathbf{V}^l_{\text{risk}}.^{10} \tag{2}$$

Next, we extract the embedding of each explanation in the human response data and the GPT4-generated data. We decompose the meaning of each explanation into three components: return-related, risk-related, and other. Given an embedding vector $\mathbf{emb}_i$ of explanation i, the decomposition can be computed as

$$\mathbf{emb}_i = \mathrm{c}_{i,r}\mathbf{V}_{\text{ret}} + \mathrm{c}_{i,v}\mathbf{V}_{\text{risk}} + \epsilon_i, \tag{3}$$

where $c_{i,r}$ is the projection coefficient of $\mathbf{emb}_i$ onto $\mathbf{V}_{\text{ret}}$, $c_{i,v}$ is the projection coefficient onto $\mathbf{V}_{\text{risk}}$, and ϵ_i is the remaining vector component that does not correspond to either the return vector or the risk vector. Intuitively, $c_{i,r}$ is explanation i's association with high return, and $c_{i,v}$ is i's association with high risk.

We begin by confirming that explanations generated by GPT4 align with human responses in terms of the relative ordering of the asset classes (stocks, bonds, and cash) along the return and risk dimensions. Both human participants' and GPT4-generated explanations have, on average, the highest return components when explaining rankings of stocks, followed by bonds, then cash. Similarly, both human and GPT4-generated explanations project the highest risk when discussing stocks, followed by cash, and then bonds. Overall, GPT4's relative discussion of stocks, bonds, and cash along both risk and return axes is consistent with the verbal explanations provided by human survey participants.[11]

Next, we combine the information from the free-form explanations and the ratings on different investment options generated by humans and GPT4 to estimate the correlation

[10] We find that these two axes ($\mathbf{V}_{\text{ret}}$ and $\mathbf{V}_{\text{risk}}$) are nearly orthogonal with an angle of 70 degrees.

[11] Some real examples of explanations with high and low projection scores are shown in Table A2 in the Online Appendix.

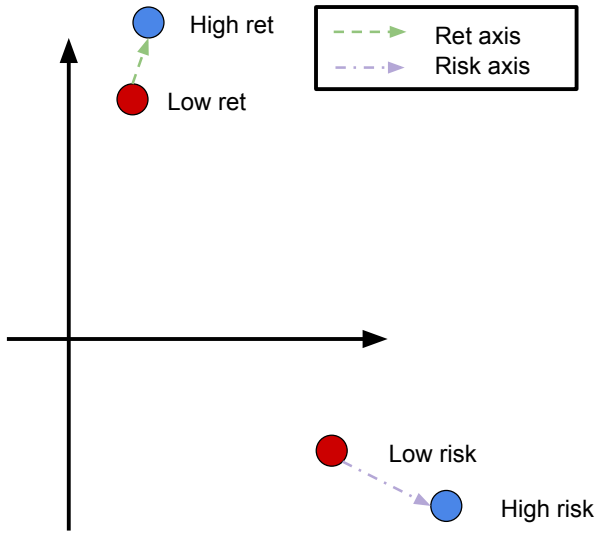


Figure 2: This is a two-dimensional illustration of the risk-return embeddings. The blue dots are the positions corresponding to the embedding vectors of the two sentences describing an asset with high return and high risk, respectively. The two red dots correspond to low return and risk, respectively. The two dashed arrows represent the direction of the return axis and risk axis from low to high. The positions of the dots are only for illustrative purposes. The actual embeddings are 1536-dimensional.

between the perceived risk and return and the stated rating of each investment option across human participants and GPT4 responses. This analysis accomplishes two goals: (i) to observe the extent to which the categorical ratings are explained by risk and return considerations, and (ii) to test whether the relationship between categorical ratings and free-form discussions of risk and return in actual human survey responses is reflected in responses generated by GPT4. To address these questions, we estimate the following specification:

$$\begin{aligned}\text{Rating}_{i,k} =& \beta_1 c_{i,k,r} + \beta_2 c_{i,k,v} + \beta_3 \mathbb{1}(\text{i is a GPT4 agent}) \\ &+ \beta_4 \mathbb{1}(\text{i is a GPT4 agent}) * c_{i,r} + \beta_5 \mathbb{1}(\text{i is a GPT4 agent}) * c_{i,r} + \delta_k + \epsilon_{i,k}, \quad (4)\end{aligned}$$

where $\text{Rating}_{i,k}$ is participant i's rating of investment option $k \in \{\text{stocks}, \text{bonds}, \text{cash}\}$, standardized to have a mean of zero and a standard deviation of one. $c_{i,,k,r}$ and $c_{i,k,v}$ are the projections of participant i's free-form responses regarding investment option k

onto the return (r) and risk (v) space, likewise standardized to have a mean of zero and a standard deviation of one. $\delta_{i,k}$ is a fixed effect that denotes the type of investment (stocks, bonds, or cash). The coefficient β_1 (β_2) can be interpreted as the importance of return (risk) for humans' ratings of the investment options, and β_4 (β_5) can be interpreted as the under- or overstatement of the importance of return (risk) by GPT4.

	Dependent variable:
	rating
return	0.788^{***}
	(0.015)
generated by GPT4	-0.172^{***}
	(0.017)
risk	-0.564^{***}
	(0.017)
GPT4 bias: return	-0.017
	(0.019)
GPT4 bias: risk	0.053^{***}
	(0.020)
Observations	6,348
R^2	0.554
Adjusted R^2	0.554
Residual Std. Error	0.668 (df = 6340)
Note:	*p<0.1; **p<0.05; ***p<0.01

TABLE 4: Statistical analysis of the correlations between risk and return projections of free-form explanations and the categorical ratings. This table shows the correlations based on human data and the differences in the correlations between the human and GPT4-generated data.

The results are presented in Table 4. Understandably, a higher perceived return-generating potential of an asset in the free-form responses is significantly positively correlated with higher categorical ratings for that asset. In the human survey, a one-standard-deviation increase in the perceived return is associated with a 0.79 standard deviation

increase in the rating. In addition, higher perceived risk in free-form responses is significantly negatively associated with categorical ratings. A one-standard-deviation increase in perceived risk in human survey responses is associated with a 0.56 standard deviation decrease in the associated rating.

The GPT4 responses yield a very similar correlation between ratings and returns, with no significant bias. GPT4 responses do show a slightly weaker relationship between ratings and risk than human responses; however, the magnitude of the coefficient (0.05) is very small. Overall, the free-form responses capture important information about the reasoning behind the ratings, with high correlations between categorical ratings and the loadings on return (positive) and risk (negative) in the free-form responses. Most importantly, we observe that responses generated by GPT4 closely match human responses in terms of the "reasoning" behind the ratings, with very similar relationships between ratings and risk/return across the actual human survey responses and the GPT4-generated responses.

4.3 Other themes in free-form responses

So far, we have examined the two major common themes in free-form responses (both from human survey participants and GPT4), risk and return. We now investigate which other auxiliary themes play a role in the data, and to which extent these agree between human survey data and GPT4-generated responses. We focus specifically on explanations for stock ratings, to see whether we can speak to the drivers of low stock market participation, which is a long-standing and significant issue documented by the prior literature (Guiso, Sapienza and Zingales, 2008; Van Rooij, Lusardi and Alessie, 2011).[12]

To do so, we go beyond the most common single terms (unigrams) and use the full text

[12] Although our main focus with the auxiliary free-form response analysis is on stocks due to the central role of the low stock market participation issue, for completeness, we provide analogous analysis of the auxiliary themes of investing in bonds (where knowledge is the main theme emerging from the summarization) and cash (where the most consistent theme is the convenience/accessibility of cash) in Online Appendix F.

of the responses to capture potential themes conveyed by phrases or sentences. Specifically, we combine *all* of the explanations about a specific investment option (e.g., stocks) from human survey participants and divide these explanations into two subsets: explanations associated with negative ratings (< 3) and explanations associated with positive ratings (> 3). We then use GPT4's summarization capabilities to answer the following prompt based on the two subsets of positive/negative explanations:

> *Read the following two sets of opinions about investing in stocks and describe 5 themes other than risk and return that are different between the two sets using 5 short phrases:*
> *set 1:... (explanations of positive ratings)*
> *set 2:... (explanations of non-positive ratings)*

This gives the main five auxiliary themes in the human response data. Then we use the same prompt to identify the auxiliary themes based on the responses generated by GPT4. We repeat the procedure three times to ensure that we obtain consistent, replicable summaries and do not capture statistical noise; the themes from each run are listed in Table A3 in the Online Appendix.

In all summaries, the themes in both the human and GPT4-generated data prominently feature the topic of "knowledge" (financial literacy and understanding of the stock market). Specifically, human data are summarized by the themes "Perception of Complexity and Accessibility" (first run), "Understanding and Accessibility" (second run), and "Perception of Complexity" (third run); similarly, GPT4-generated responses reflect the themes "Knowledge and Complexity" (second and third run). Beyond knowledge and understanding, one other theme that appears frequently in both human and GPT4-generated data is "experience" (positive or negative emotional reactions to past experiences with the stock market). Human survey responses include themes such as "Emotional Response" (first run), "Influence of Past Experience" (second run), and "Emotional and Psychological Experience" (third run), while GPT4-generated responses include themes such as "Emotional and Psychological Responses" (first run) and "Emotional Response and Comfort Level" (second run).

First, we focus on the knowledge and understanding dimension. We use the Semantic Axis approach discussed in Section 4.1 to compute each response's relevance score to the knowledge theme. In particular, we define the knowledge dimension using the embeddings of the following two sentences:

- "I am very knowledgeable about the stock market." (high knowledge)
- "I do not know anything about the stock market." (low knowledge)

Following the procedure discussed in Section 4.1, we use the difference between the embeddings of these two sentences as a numerical representation of the knowledge dimension. Then, we project the embedding of each explanation accompanying a given (human or GPT4-generated) rating about investing in stocks onto this axis to compute its relevance to knowledge about the stock market. Figure 3 shows a graphical representation of this projection, in blue for the explanations provided by human participants and in yellow for the explanations generated by GPT4.

Both projections center just below zero, with tails in both positive and negative directions. GPT4-generated responses show a clear bimodal distribution and smaller tales, while the human responses are less bimodal and have longer tails. We use an expectation-maximization algorithm with two clusters to group data points to their corresponding clusters, where one cluster (positive) reflects the presence of knowledge regarding stocks, and the second cluster (negative) reflects the absence of knowledge or understanding. We identify the clusters using a Gaussian Mixture Model, modeling each set of knowledge projections (from human and GPT4-generated explanations) using a data-generating process that randomly picks individuals from two Gaussian distributions (one for each cluster) with some fixed probabilities. Mathematically, the clustering algorithm can be written as the following optimization problem:

1. Let $\boldsymbol{\mu} = (\mu_1, \mu_2, \cdots, \mu_m)$ be the initial means of the m clusters, $\boldsymbol{\Sigma} = (\Sigma_1, \Sigma_2, \cdots, \Sigma_m)$ be the initial covariance matrices, and $\boldsymbol{\pi} = (\pi_1, \pi_2, \cdots, \pi_m)$ be the initial mixing

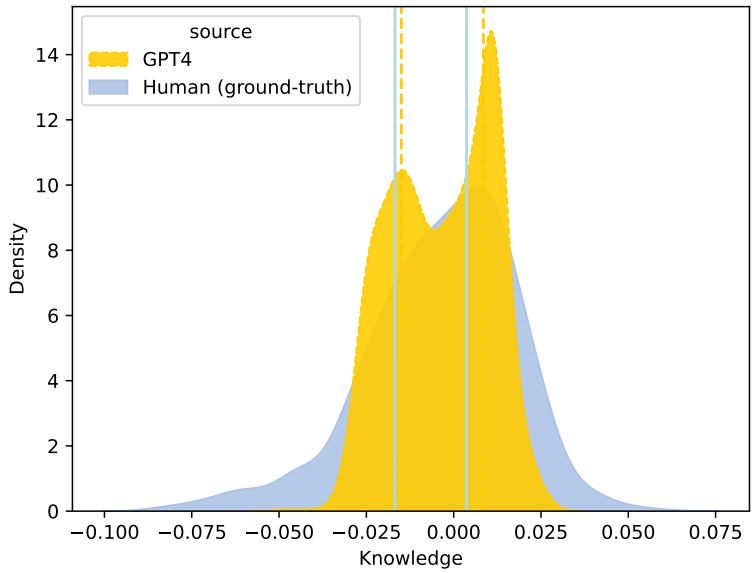


Figure 3: The density of GPT4 and human responses' relevance to having a high amount of knowledge about the stock market. The blue density plot represents the human data, and the yellow plot represents the GPT4 data. The dotted vertical lines represent the centers of the three clusters of GPT4 data and the continuous vertical lines are the centers of the three clusters of the human data.

coefficients.

2. Calculate the responsibility r_{ik} for each data point i and each cluster k using the current parameter estimates:

$$r_{ik} = \frac{\pi_k \phi_k(\mathbf{x_i})}{\sum_{j=1}^{m} \pi_j \phi_j(\mathbf{x_i})},$$

where ϕs are the PDF of the estimated multivariate Gaussian distributions.

3. Update the parameters:

$$\boldsymbol{\mu}_k^{new} = \frac{\sum_{i=1}^{N} r_{ik}\mathbf{x}_i}{\sum_{i=1}^{N} r_{ik}},$$
$$\boldsymbol{\Sigma}_k^{new} = \frac{\sum_{i=1}^{N} r_{ik}(\mathbf{x}_i - \boldsymbol{\mu}_k^{new})(\mathbf{x}_i - \boldsymbol{\mu}_k^{new})^T}{\sum_{i=1}^{N} r_{ik}},$$
$$\pi_k^{new} = \frac{1}{N}\sum_{i=1}^{N} r_{ik}.$$

4. Repeat the above two steps until convergence.[13]

The resulting clusters are displayed in Figure 3, in solid blue vertical lines for the human survey explanations and dashed yellow vertical lines for the GPT4-generated explanations. The clusters of explanations generated by GPT4 are slightly more positive than those of the human survey participants—cluster centers are slightly further on the right—but the clusters are qualitatively similar. In both cases, cluster 1 (containing explanations of stock ratings that reflect a low amount of knowledge about the stock market) is around -0.015, and cluster 2 (which contains explanations conveying a high level of knowledge about the stock market) is around 0.007. The absence of knowledge and understanding of the stock market is somewhat more prevalent in the GPT4 data than in human responses: in the human distribution, the low knowledge cluster contains 35% of the individuals, and in the GPT4 distribution, the corresponding cluster contains 50% of the agents.

In Table 5, we examine how knowledge levels vary across demographic characteristics, and whether these patterns are correctly reflected by GPT4. In particular, we consider the cluster label of each agent as its type. This is motivated by the underlying assumption that there are two types of individuals in terms of knowledge about the stock market: the uninformed respondents are randomly drawn from the negative cluster and the knowledgeable respondents are randomly drawn from the positive cluster. For each data set

[13]The convergence tolerance we use is 0.0001. In our analyses, all optimizations converge with fewer than 100 iterations. For more details about Gaussian Mixture Models and other finite mixture models, refer to McLachlan, Lee and Rathnayake (2019).

(embeddings of human responses and embeddings of GPT4-generated responses), we regress the cluster label (cluster 1 or 2) against the three demographic characteristics: age, gender, and income. The resulting coefficients estimated on the projections of human responses show that the answers of men and higher-income individuals reflect a higher level of knowledge about the stock market. Similar patterns hold in GPT4-generated data: simulated male responses reflect higher levels of knowledge (with a statistically indistinguishable coefficient to the human data), and simulated responses of higher-income individuals likewise reflect greater knowledge of the stock market (with a more substantial difference than in the human data). Explanations generated by GPT4 are also more likely to project higher knowledge of the stock market from younger individuals, although the association between age and knowledge in the actual survey responses is null.

	Dependent variable:	
	Knowledge about the stock market (cluster label)	
	Human	GPT4
age	-0.001	-0.015^{***}
	(0.001)	(0.002)
gender	-0.092^{***}	-0.082^{***}
	(0.025)	(0.027)
income	0.002^{***}	0.058^{***}
	(0.0004)	(0.003)
Observations	1,074	1,042
R^2	0.045	0.241
Adjusted R^2	0.043	0.239
Residual Std. Error	0.403 (df = 1070)	0.436 (df = 1038)
F Statistic	16.893^{***} (df = 3; 1070)	109.795^{***} (df = 3; 1038)
Note:		*p<0.1; **p<0.05; ***p<0.01

TABLE 5: This table shows the correlations between age, gender, and income and the knowledge about the stock market reflected in free-form responses, for human responses in the left column and GPT4-generated responses in the right column. Income is scaled in thousands of dollars.

Second, we conduct similar analyses along the "personal experience" dimension. We

use the difference between the embeddings of the following two descriptions to compute a numerical representation of the personal investing experience dimension:

- "I have had very good experiences investing in the stock market." (positive experience)
- "I have had terrible experiences investing in the stock market." (negative experience)

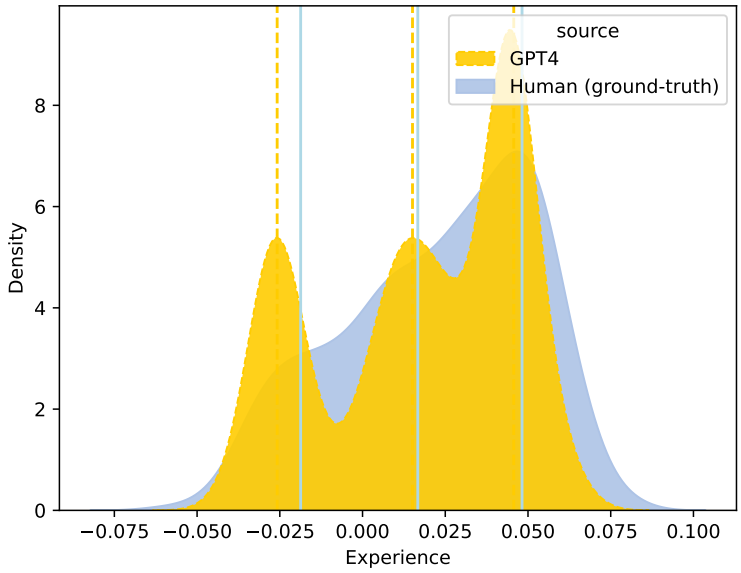


Figure 4: The density of GPT4-generated responses' and human responses' relevance to positive experiences with the stock market. The blue density plot represents the human data, and the yellow plot represents the GPT4-generated data. The continuous vertical lines mark the centers of the three clusters of human responses, and the dotted vertical lines mark the centers of the three clusters of responses generated by GPT4.

Figure 4 shows the resulting projections, and we apply the same approach as we did for the knowledge theme (i.e., a Gaussian Mixture Model) to cluster these distributions, defining three clusters corresponding to more positive experiences, more negative experiences, and neutral experiences. The solid blue vertical lines in Figure 4 mark the centers of the three clusters for the experience projections of human responses, and the

dotted yellow vertical lines represent the centers of the three clusters for the projections of GPT4-generated responses.

In each data set, there is one cluster with responses reflecting negative past experiences with the stock market, centered around -0.023, one with mildly positive experiences, centered around 0.018, and one with very positive experiences, centered around 0.049. Moreover, the distributions across the three clusters are very similar between human and GPT4-generated responses. 23% of human explanations (24% of GPT4-generated explanations) are in the cluster associated with negative experiences with the stock market, 33% of human explanations (35% of GPT4-generated explanations) are in the cluster with slightly positive experiences, and 44% of human explanations (41% of GPT4-generated explanations) are in the cluster with strongly positive experiences with the stock market.

	Dependent variable:	
	Experience with the stock market (cluster label)	
	Human	GPT4
age	-0.004^{**}	-0.027^{***}
	(0.002)	(0.003)
gender	-0.201^{***}	-0.093^{**}
	(0.047)	(0.041)
income	0.003^{***}	0.110^{***}
	(0.001)	(0.005)
Observations	1,074	1,042
R^2	0.037	0.335
Adjusted R^2	0.035	0.333
Residual Std. Error	0.774 (df = 1070)	0.648 (df = 1038)
F Statistic	13.866^{***} (df = 3; 1070)	174.154^{***} (df = 3; 1038)
Note:		*p<0.1; **p<0.05; ***p<0.01

TABLE 6: This table shows the correlations between age, gender, and income and human participants' (GPT4 agents') experience with the stock market. Income is scaled in thousands of dollars.

We examine how reported personal experiences with the stock market vary across de-

mographics, and whether GPT4 is able to capture those differences. We regress the cluster labels (1 for the negative experience cluster, 2 for mildly positive experiences, and 3 for strongly positive experiences) on age, gender, and income of the corresponding human participant or simulated GPT4 agent. Table 6 reports the results. Column 1, which reflects actual human responses, shows that younger individuals tend to have more positive experiences with the stock market than older individuals, males tend to have more positive experiences than females, and higher-income individuals tend to have more positive experiences than lower-income individuals. All of the coefficients are significant at the 5% level or more. Column 2 shows that, while the coefficients are different, the directional patterns are the same in GPT4 data: simulated younger individuals, men, and individuals with higher incomes generate explanations that project more positive experiences with the stock market.

Together, Tables 5 and 6 show that there are strong demographic patterns in the expressions of both knowledge and personal experiences of the stock market and that GPT4 is effective at capturing these directional patterns across demographics.

4.4 Connection between risk-return perception, past experience, and financial literacy

So far, we observe that risk, return, experience, and knowledge are the major themes in explanations of attitudes towards the stock market. Both human and GPT4-generated ratings of stocks as an asset class are correlated with these factors, and the directional correlations are aligned. We now explore how these four themes (risk, return, knowledge, and experience) relate to each other.

We analyze the correlations between the projections computed in the previous two subsections. Specifically, we have four sets of projections, each corresponding to a theme. For example, a higher projection on the return dimension corresponds to a free-form response indicating a higher expectation of stocks' returns, while a higher projection on the

experience dimension corresponds to a free-form response reflecting positive experiences investing in stocks.

Using these projection values, we test the following set of hypotheses using the corresponding regressions:

1. A higher value on the knowledge dimension (i.e., financial literacy) correlates with a lower risk perception.

2. A higher value on the knowledge dimension (i.e., financial literacy) correlates with a higher return perception.

3. More positive past investment experiences correlate with a lower risk perception.

4. More positive past investment experiences correlate with a higher return perception.

5. More positive past investment experiences correlate with a higher value of reported knowledge/familiarity (financial literacy).

We test each of these hypotheses in Table 7, using the responses from our human investment survey and including fixed effects for demographic characteristics (age, gender, and income). The correlations are significant in the directions predicted: both knowledge and (positive) past experiences translate into higher expectations of stock returns and lower perception of risk. Knowledge about the stock market is also strongly positively correlated (at 86%) with positive past experiences. Critically, all of these patterns are correctly captured by GPT4. Table 8 repeats the analysis in Table 7 on the GPT4-generated responses, replicating the same correlations. This result shows that GPT4 correctly captures the structure of reasoning behind investment preferences, reflecting how key themes translate into categorical ratings and the cross-relationships between themes.

	Dependent variable:				
	return		risk		knowledge
	(1)	(2)	(3)	(4)	(5)
experience	0.675***		-0.489***		0.858***
	(0.018)		(0.027)		(0.026)
knowledge		0.576***		-0.166***	
		(0.015)		(0.026)	
Observations	1,074	1,074	1,074	1,074	1,074
R^2	0.666	0.670	0.344	0.154	0.603
Adjusted R^2	0.619	0.623	0.252	0.034	0.547
Residual Std. Error (df = 940)	0.545	0.542	0.818	0.930	0.793

Note: *p<0.1; **p<0.05; ***p<0.01

TABLE 7: This table shows the correlations between the four main themes in textual explanations of human survey participants' stock ratings: risk, return, experience, and knowledge (financial literacy). The correlations are computed with fixed effects for participant gender, age, and income.

5 Are humans and GPT4 transitive?

A necessary condition for economic preferences to be considered rational is transitivity. For example, if a rational consumer prefers stocks over bonds and bonds over cash, then they must also prefer stocks over cash. In this section, we examine the transitivity property of human and GPT4-generated preference orderings. For this analysis, we leverage the relative-comparison responses, where participants were asked to directly order pairs of investment options within each question. For example, when we elicit preferences between stocks and bonds, we allow participants to choose one of three responses: stocks, bonds, or indifferent.

	Dependent variable:				
	return		risk		knowledge
	(1)	(2)	(3)	(4)	(5)
experience	0.861***		-0.324***		0.678***
	(0.016)		(0.027)		(0.014)
knowledge		0.960***		-0.293***	
		(0.024)		(0.034)	
Observations	1,042	1,042	1,042	1,042	1,042
R^2	0.850	0.772	0.164	0.110	0.806
Adjusted R^2	0.848	0.768	0.149	0.094	0.802
Residual Std. Error (df = 1023)	0.384	0.474	0.659	0.680	0.344

Note: *p<0.1; **p<0.05; ***p<0.01

TABLE 8: This table shows the correlations between the four main themes in textual explanations of GPT4-generated stock ratings: risk, return, experience, and knowledge (financial literacy). The correlations are computed with fixed effects for participant gender, age, and income.

To test whether each individual's preference satisfies transitivity, we use the following proposition:

Proposition 1 *Let* $a \in \{stocks, bonds, indifferent\}$, $b \in \{stocks, cash, indifferent\}$, *and* $c \in \{cash, bonds, indifferent\}$ *be the three responses provided by a survey participant to the three relative-preference questions. The participant's preference ordering satisfies transitivity if and only if the following conditions are met:*

1. *If* $a, b, c \neq$ *indifferent, exactly one of the following must be true* $a = b$ *or* $b = c$ *or* $a = c$.
2. *If* $a =$ *indifferent, then either* $b = c$ *or* $b, c \in \{stocks, bonds\}$.
3. *If* $b =$ *indifferent, then either* $a = c$ *or* $a, c \in \{cash, stocks\}$.

4. *If c = indifferent, then either $a = b$ or $a, b \in \{cash, bonds\}$.*

Applying proposition 1, we find that overall, 84.4% of human survey responses and 98.7% of GPT4-generated responses follow transitivity. This means that GPT4 agents' preferences are almost always transitive, while human responses may not be. We further investigate the cause of this discrepancy between humans and simulated GPT4 agents. In particular, we study the source of intransitivity in the human data set.

We start by dividing the human sample into responses from men and women. As shown in Table 9, we observe that within the male subsample, 89.5% of the participants have transitive preferences, and within the female subsample, only 79.1% of the respondents satisfy transitivity. Furthermore, we observe that conditioning on human participants with no "indifferent" responses, 95.7% of these participants have transitive preferences. However, conditioning on participants with at least one "indifferent" response, only 72.0% of human participants have transitive preferences.[14]

Combining these two observations, we investigate whether the lower proportion of female participants with transitive preferences is due to an imbalanced distribution of participants who respond with at least one "indifferent." Indeed, we find 40.3% of male human participants with at least one indifference, while the proportion of female participants with at least one indifference is 55.7%. In addition, we observe that conditioning on the human participants who responded with at least one indifference, males are still more likely to have transitive preferences than females: 79.0% of men compared to 66.8% of women. Among participants with no "indifferent" responses, the share of transitive preference orderings is not statistically different between men (96.6%) and women (94.5%). In both genders, this share is lower than the share of simulated GPT4 agents with transitive preference.

Overall, we make four observations related to the rationality of expressed preference

[14]Note that no simulated GPT4 agent responded with "indifferent" despite being provided this option. This is potentially because GPT4 is trained to produce answers that are preferred by human requesters, and when a human asks GPT4 to make a selection, "indifferent" is usually not a desirable answer.

	GPT4		Human			
n obs	1042		1074			
transitive prob	98.7%		84.4%			
difference	14.3%***					
	Male	**Female**	**Male**		**Female**	
n obs	500	542	544		530	
transitive prob	99.8%	97.6%	89.5%		79.1%	
difference	2.2%***		10.4%***			
			diff	**indiff**	**diff**	**indiff**
n obs			325	219	235	295
transitive prob			96.6%	79.0%	94.5%	66.8%
difference			17.6%***		27.7%***	

TABLE 9: Preference transitivity of human participants and simulated GPT4 agents. In this table, the "diff" columns report the results conditioned on the subset of human participants who did not respond with "indifferent" to any of the three preference questions. The "indiff" columns report the results conditioned on the subset of human participants who responded with "indifferent" to at least one of the three preference questions.

orderings:

1. GPT4 agents almost always have transitive preference orderings over investing in stocks, bonds, and cash, but human survey participants are less likely to have transitive preference orderings.

2. The main driver of non-transitive preferences in human survey respondents is the presence of at least one indicated indifference between investment options.

3. There is a gender difference in transitive preferences, whereby men display more transitive orderings than women. This is driven by both the frequency of indifference (higher in women than in men) and the likelihood of violating transitivity conditional on having at least one indifferent response (33.2% for women vs. 21.0% for men).

4. Even among male human participants with no indifferent responses (the group of human participants with the highest share of transitive preference orderings), the

share of transitive preference orderings is still lower than that of simulated GPT4 agents, but this difference is smaller in both size and statistical significance (96.6% vs. 99.8%).

6 Conclusion

We examine how well generative AI (as exemplified by OpenAI's GPT4) can replicate human investment preferences, especially across demographics. Algorithmic bias is becoming an increasingly salient issue with the rise of machine learning in finance. For example, Bartlett et al. (2022) showcase concerns in the credit space, and multiple banks such as Wells Fargo have been sued for using AI models that led to discriminatory lending. Our results show a more positive side of AI: in the context of predicting investment preferences, generative AI does not seem to suffer from systematic bias and correctly captures heterogeneity across gender, age, and income—as long as the model is queried with demographic input. This key finding holds for both investment preferences and actual asset allocations. Furthermore, not only are GPT4-generated ratings of investment options highly correlated with actual survey participants' ratings, but GPT4 also has similar "reasoning": it captures the main themes in free-form explanations, how these themes relate to the categorical ratings, and how these themes interact with each other.

Our results have significant implications for the financial services industry, especially regarding the rising prominence of robo-advising in the investment management space (D'Acunto, Prabhala and Rossi, 2019; Rossi and Utkus, 2021). Our analysis suggests that the recent advances in generative AI will enable further growth for these types of automated investment advice services, correctly capturing heterogeneous preferences across investor demographics while avoiding pitfalls such as non-transitive rankings. As the investment landscape becomes not only more automated but also more diverse, with growing shares of small and retail investors, the ability to accurately reflect cross-demographic

heterogeneity in investment preferences, attitudes, and experiences will be a crucial feature for successful applications of AI in finance.

References

Abis, Simona, and Laura Veldkamp. 2024. "The changing economics of knowledge production." *The Review of Financial Studies*, 37(1): 89–118.

Agnew, Julie, Pierluigi Balduzzi, and Annika Sunden. 2003. "Portfolio choice and trading in a large 401 (k) plan." *American Economic Review*, 93(1): 193–215.

An, Jisun, Haewoon Kwak, and Yong-Yeol Ahn. 2018. "SemAxis: A Lightweight Framework to Characterize Domain-Specific Word Semantics Beyond Sentiment." 2450–2461. Melbourne, Australia:Association for Computational Linguistics.

Babina, Tania, Anastassia Fedyk, Alex He, and James Hodson. 2024. "Artificial intelligence, firm growth, and product innovation." *Journal of Financial Economics*, 151: 103745.

Barber, Brad M, and Terrance Odean. 2001. "Boys will be boys: Gender, overconfidence, and common stock investment." *The Quarterly Journal of Economics*, 116(1): 261–292.

Barber, Brad M, Xing Huang, Terrance Odean, and Christopher Schwarz. 2022. "Attention-induced trading and returns: Evidence from Robinhood users." *The Journal of Finance*, 77(6): 3141–3190.

Bartlett, Robert, Adair Morse, Richard Stanton, and Nancy Wallace. 2022. "Consumer-lending discrimination in the FinTech era." *Journal of Financial Economics*, 143(1): 30–56.

Bertomeu, Jeremy, Yupeng Lin, Yibin Liu, and Zhenghui Ni. 2023. "Capital Market Consequences of Generative AI: Early Evidence from the Ban of ChatGPT in Italy." *Available at SSRN 4452670*.

Brown, Tom, Benjamin Mann, Nick Ryder, Melanie Subbiah, Jared D Kaplan, Prafulla Dhariwal, Arvind Neelakantan, Pranav Shyam, Girish Sastry, Amanda Askell, et al. 2020. "Language models are few-shot learners." *Advances in neural information processing systems*, 33: 1877–1901.

Brynjolfsson, Erik, Danielle Li, and Lindsey R Raymond. 2023. "Generative AI at Work." National Bureau of Economic Research.

Buolamwini, Joy, and Timnit Gebru. 2018. "Gender shades: Intersectional accuracy disparities in commercial gender classification." 77–91, PMLR.

Bybee, J Leland. 2023. "The Ghost in the Machine: Generating Beliefs with Large Language Models." Yale University Working Paper.

Cao, Sean, Wei Jiang, Junbo L Wang, and Baozhong Yang. 2021. "From man vs. machine to man + machine: The art and AI of stock analyses." *Columbia Business School Research Paper*.

D'Acunto, Francesco, Pulak Ghosh, and Alberto G Rossi. 2022. "How costly are cultural biases? Evidence from fintech." *Working Paper*.

D'Acunto, Francesco, Nagpurnanand Prabhala, and Alberto G Rossi. 2019. "The promises and pitfalls of robo-advising." *The Review of Financial Studies*, 32(5): 1983–2020.

Eisfeldt, Andrea L, Gregor Schubert, Bledi Taska, and Miao Ben Zhang. 2023. "Generative AI and Firm Values." National Bureau of Economic Research.

Eloundou, Tyna, Sam Manning, Pamela Mishkin, and Daniel Rock. 2023. "GPTs are GPTs: An early look at the labor market impact potential of large language models." *arXiv preprint arXiv:2303.10130*.

Fedyk, Anastassia, and James Hodson. 2023. "When can the market identify old news?" *Journal of Financial Economics*, 149(1): 92–113.

Fedyk, Anastassia, James Hodson, Natalya Khimich, and Tatiana Fedyk. 2022. "Is artificial intelligence improving the audit process?" *Review of Accounting Studies*, 27(3): 938–985.

Fuster, Andreas, Paul Goldsmith-Pinkham, Tarun Ramadorai, and Ansgar Walther. 2022. "Predictably unequal? The effects of machine learning on credit markets." *The Journal of Finance*, 77(1): 5–47.

Guiso, Luigi, Paola Sapienza, and Luigi Zingales. 2008. "Trusting the stock market." *the Journal of Finance*, 63(6): 2557–2600.

Hansen, Anne Lundgaard, and Sophia Kazinnik. 2023. "Can chatgpt decipher fedspeak." *Available at SSRN*.

Hochberg, Yael, Ali Kakhbod, Peiyao Li, and Kunal Sachdeva. 2023. "Inventor Gender and Patent Undercitation: Evidence from Causal Text Estimation." National Bureau of Economic Research.

Hong, Harrison, Jeffrey D Kubik, and Jeremy C Stein. 2004. "Social interaction and stock-market participation." *The Journal of Finance*, 59(1): 137–163.

Horton, John J. 2023. "Large language models as simulated economic agents: What can we learn from homo silicus?" National Bureau of Economic Research.

Kadambi, Achuta. 2021. "Achieving fairness in medical devices." *Science*, 372(6537): 30–31.

Li, Edward Xuejun, Zhiyuan Tu, and Dexin Zhou. 2023. "The Promise and Peril of Generative AI: Evidence from ChatGPT as Sell-Side Analysts." *Available at SSRN 4480947*.

Lopez-Lira, Alejandro, and Yuehua Tang. 2023. "Can chatgpt forecast stock price movements? Return predictability and large language models." *arXiv preprint arXiv:2304.07619*.

Loughran, Tim, and Bill McDonald. 2014. "Measuring readability in financial disclosures." *the Journal of Finance*, 69(4): 1643–1671.

Malmendier, Ulrike, and Stefan Nagel. 2011. "Depression babies: Do macroeconomic experiences affect risk taking?" *The Quarterly Journal of Economics*, 126(1): 373–416.

Malmendier, Ulrike, and Stefan Nagel. 2016. "Learning from inflation experiences." *The Quarterly Journal of Economics*, 131(1): 53–87.

McLachlan, Geoffrey J, Sharon X Lee, and Suren I Rathnayake. 2019. "Finite mixture models." *Annual Review of Statistics and Its Application*, 6: 355–378.

Noy, Shakked, and Whitney Zhang. 2023. "Experimental evidence on the productivity effects of generative artificial intelligence." *Available at SSRN 4375283*.

Reher, Michael, and Stanislav Sokolinski. 2024. "Robo Advisors and Access to Wealth Management." *Journal of Financial Economics*, Forthcoming.

Rossi, Alberto G, and Stephen P Utkus. 2021. "Who benefits from robo-advising? Evidence from machine learning." *working Paper*.

Tetlock, Paul C. 2007. "Giving content to investor sentiment: The role of media in the stock market." *The Journal of finance*, 62(3): 1139–1168.

Van Rooij, Maarten, Annamaria Lusardi, and Rob Alessie. 2011. "Financial literacy and stock market participation." *Journal of Financial Economics*, 101(2): 449–472.

Veldkamp, Laura. 2023. "Valuing data as an asset." *Review of Finance*, 27(5): 1545–1562.

Welch, Ivo. 2022. "The wisdom of the Robinhood crowd." *The Journal of Finance*, 77(3): 1489–1527.

Zou, James, and Londa Schiebinger. 2018. "AI can be sexist and racist—it's time to make it fair."

Online Appendix

A Additional Tables

15 most frequent nouns in human responses		15 most frequent nouns in GPT4 responses	
Noun	**Count**	**Noun**	**Count**
investment	474	return	1408
money	421	growth	549
return	295	risk	508
way	255	offer	322
risk	220	income	256
value	179	potential	180
inflation	175	investment	169
time	168	lack	132
market	141	liquidity	105
term	123	stability	104
option	106	inflation	94
interest	105	security	79
choice	99	safety	76
lot	98	time	64
rate	85	yield	59

TABLE A1: Top 15 most frequent nouns in GPT4 and human responses after removing stop words. The ones colored green are characteristics used to describe an investment option.

	High	Low
Risk		
	• potential for high returns, higher risk. • This is because of the high risk involved in this kind of investment.	• Cash is low risk and allows the investor to have access to his/her cash when needed. • cash investments are low risk.
Return		
	• They offer the highest return on your investment even with higher risk. • Stocks have the ability to offer higher gains so I like these investments.	• low potential for growth. • Cash is less likely to gain value.
Knowledge		
	• I am a financial advisor and I know how to analyze investments. • I have more knowledge about stocks and therefore feel more positively towards them.	• I don't know anything about stocks. • I do not know enough about the stock market.
Experience		
	• I've found it positive, and have a had a decent experience thus far with it. • I have had good return with stock investment.	• Too unpredictable and corrupt. • I hate the stock market.

TABLE A2: This table shows some examples of explanations that received the highest or lowest projection scores along risk, return, knowledge, and experience dimensions. All of the examples in the high column are selected from the five highest-rated markings of the corresponding investment option and the ones in the low column are selected among the five lowest-rated markings of the corresponding investment option.

		Human Batch 1		
Perception of Complexity and Accessibility	Emotional Response	Views on Market Stability	Socioeconomic Considerations	Ethical and Societal Implications
		Human Batch 2		
Volatility Perception	Understanding and Accessibility	Attitude Towards Risk	Perceived Market Integrity	Influence of Past Experiences
		Human Batch 3		
Perception of Complexity	Volatility and Stability	Ethical and Societal Impact	Investment Approach	Emotional and Psychological Experience
		GPT4 Batch 1		
Volatility and Predictability	Income and Risk Tolerance	Perception of the Stock Market	Risk versus Reward	Emotional and Psychological Responses
		GPT4 Batch 2		
Perception of Volatility	Income Level Concerns	Market Predictability	Time Horizon	Knowledge and Complexity
		GPT4 Batch 3		
Volatility and Stability	Investment Horizon	Income Considerations	Knowledge and Complexity	Emotional Response and Comfort Level

TABLE A3: Additional themes from GPT-4 and Human Responses. We collected 3 batches of 5 themes each by using GPT4 agents' and human participants' explanations of their ratings of investing in stocks. More specifically, we asked for 5 themes (not risk and return) that differentiate low and high ratings.

B Experimental Instructions

B.1 Human Survey Instructions

Welcome to the survey on investment preferences!

In this quick survey, we are interested in learning your attitudes towards different investment options.

- You must be at least 18 years old to participate in this survey.
- You will see a series of questions about different investment options, such as stocks and bonds.
- In each question, please tell us what you think of the presented options. We are interested in your opinion, not any particular facts about those options.
- There are 6 questions in the survey, and they will take around 3-4 minutes to complete.
- After the main questions, we will also ask about your demographics, such as age and gender, to see whether different people tend to have different investment preferences.
- In appreciation of your help in this study, you will receive a $1 reward upon the completion of the entire survey.

We ensure your complete confidentiality in this survey. Your email address will only be collected for the purposes of sending your reward payment. After that, your email address will be deleted. No other identifiable information will be collected.

Participation in this survey is entirely voluntary, and you can exit the survey at any time at your sole discretion. This survey was conducted by Professor Anastassia Fedyk at UC Berkeley Haas (approved by the CPHS under protocol ID 2023-02-16039). Professor Fedyk can be reached at fedyk@berkeley.edu for any questions.

[Questions about stocks, bonds, and cash—as in the example shown in Figure B1—appear sequentially, in random order.]

[Questions with comparisons of stocks versus bonds, stocks versus cash, and bonds versus cash—following the example in Figure B2—with the order of the questions and the order in which the options are listed within each question both randomized.]

[Demographic questions screen:]

What is your gender? [Options: Male; Female; Non-binary / third gender; Prefer not to say]

What is your age?

What is your gross annual income?

B.2 Sample GPT4 Prompt

Imagine you are a male online survey participant who is below 39 years old and above 18 years old with an annual income above 54 thousand. You will be asked to answer 6 questions about your opinion of investment options such as stocks and bonds. For the first three questions please only answer with one of the following options: very positive, somewhat positive, neutral, somewhat negative, very negative. For the last three questions, please answer with one of the four options: stocks, bonds, cash, or indifferent. Give your answers in the following format:

Answer to question 1: the option you choose.

Explanation: Five to ten words of explanation of your answer.

Answer to question 2: the option you choose.

Explanation: Five to ten words of explanation of your answer.

Answer to question 3: the option you choose.

Explanation: Five to ten words of explanation of your answer.

Answer to question 4: the option you choose.

Explanation: Five to ten words of explanation of your answer.

Answer to question 5: the option you choose.

Explanation: Five to ten words of explanation of your answer.

Answer to question 6: the option you choose.

Explanation: Five to ten words of explanation of your answer.

Finally, report the age, gender, and gross annual income of your imagined identity. For example:

Age: 20

Gender: Male

Income: 60000.

Question 1: what are your views on investing in bonds?

Question 2: what are your views on investing in stocks?

Question 3: what are your views on investing in cash?

Question 4: which investment do you prefer? Stocks or cash?

Question 5: which investment do you prefer? Bonds or stocks?

Question 6: which investment do you prefer? Bonds or cash?

Correspondingly, a sample answer is

Answer to question 1: somewhat positive. Explanation: Bonds provide stable income.
Answer to question 2: very positive. Explanation: Stocks have high return potential.
Answer to question 3: neutral. Explanation: Cash has no growth potential.
Answer to question 4: stocks. Explanation: Stocks offer greater returns.
Answer to question 5: stocks. Explanation: Preference for higher return potential.
Answer to question 6: bonds. Explanation: Bonds are more secure than cash.
Age: 27 Gender: Male Income: 57000

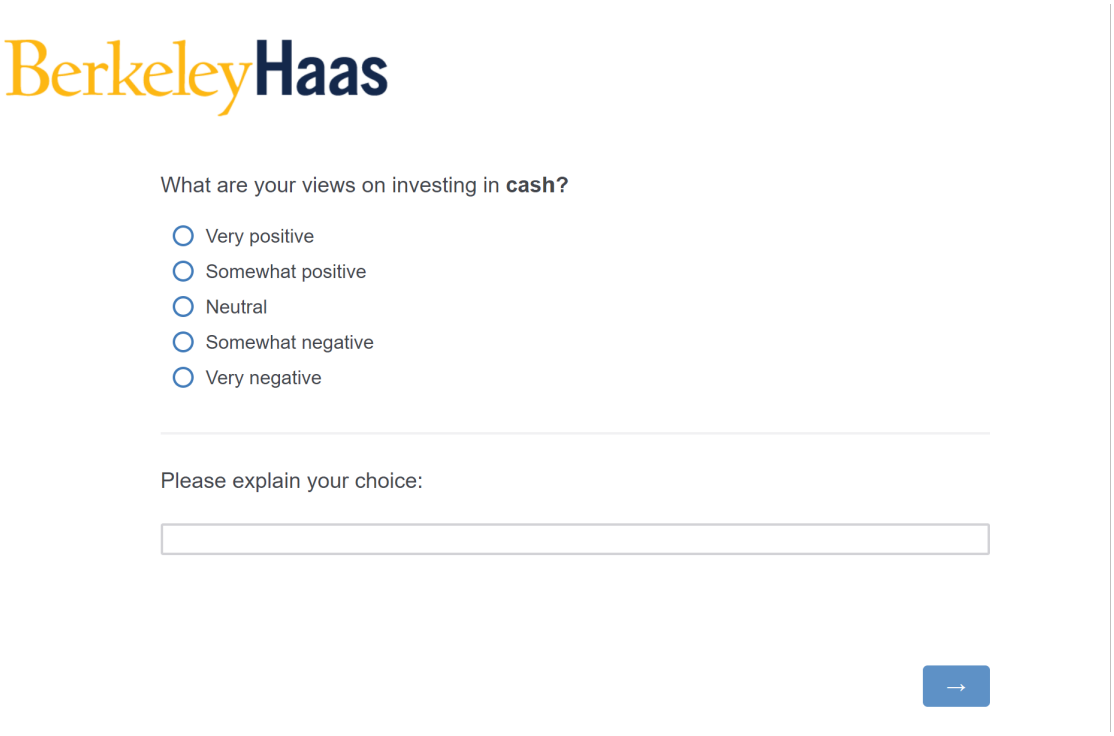


Figure B1: Screenshot of a single-rating question from the human survey.

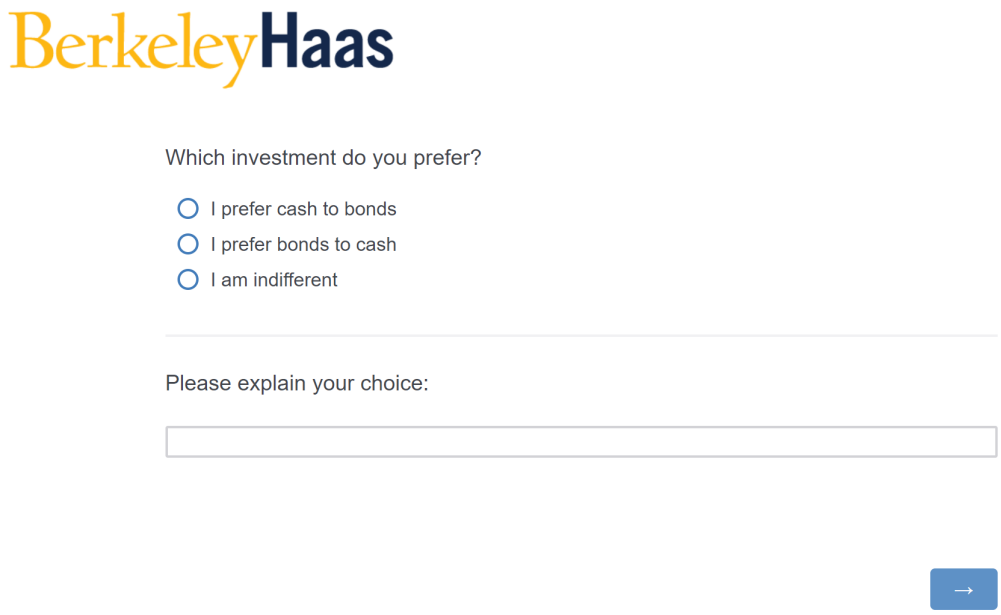


Figure B2: Screenshot of a relative-comparison question from the human survey.

C Asset allocation prompt

We detail the prompts and sample sizes we use to collect data from GPT4. To collect GPT4o-agents' asset allocations, we use the following type of prompt:

> "Imagine you are a female who is below 39 years old and above 18 years old with an annual income of at most 54 thousand dollars. First, think about your age, gender, and income. Then answer the following questions. What percent of your money would you invest in stocks, bonds, and keep as cash? Only give 6 numbers in your answer. The first three correspond to percentage in stocks, percentage in bonds, and percentage in savings, they should add up to 1. The last 3 corresponds to your age, gender (1 male, 2 female), and annual income. Use commas to separate your answers."

We vary the gender, age, and income of each agent: male versus female, above or at most 39 years old, and above or at most 54 thousand dollars of annual income.

We collect 300 samples in each of the 8 demographic categories to form a merged dataset containing 2400 responses. Similar to the main analysis, we drop data points based on the 1.5 IQR rule where data points are considered outliers if their age or income is more than 1.5 inter-quartile range away from the median. We conduct the same outlier removal step for the human survey data (SCF).

D Additional sensitivity analysis

In this section, we present additional sensitivity analyses to show that our main results hold with variations in language models and prompts.

D.1 Correlation between GPT4o-generated responses and human survey responses

	Pearson	Spearman	Kendall
All	0.886***	0.878***	0.739***
	(0.027)	(0.035)	(0.043)
Stocks	0.753***	0.810***	0.714***
	(0.100)	(0.125)	(0.130)
Bonds	0.555**	0.452**	0.286**
	(0.181)	(0.225)	(0.178)
Cash	0.689***	0.857***	0.714***
	(0.164)	(0.179)	(0.170)

TABLE D1: This table reports the Pearson, Spearman, and Kendall correlations between GPT4o-generated responses and human survey responses. These correlations are computed based on the average rating from each demographic group for the three investment options (pooled and separately). Bootstrapped (10,000 samples) standard errors are reported in parentheses.

We run the same tests as in Section 3 to assess the correlation between ratings generated by GPT4o and human survey responses. Comparing the results in Table D1 against Table 1, we see that all correlations between GPT4o-generated responses and human survey responses are at least as high as the ones between GPT4 and humans. This shows that the result—that large language models can produce financial survey results that reflect the demographic patterns of human survey respondents—is generalizable beyond a specific GPT model and that the alignment only improves with newer large language models.

Next, following the same steps as in Section 3, we use a regression model to examine the directional differences in investment preferences of demographic groups separately for human and AI-generated responses. Significant correlations in both GPT4o-generated and human survey responses are shown in table D2. Six out of seven significant correlations directionally agree. In both human survey responses and GPT4o-generated responses, older individuals rate bonds and cash higher than younger individuals, men rate stocks higher than women, and high-income earners prefer stocks and bonds, while low-income earners prefer cash. As with the baseline GPT4 model, the only source of disagreement is the differential rating of bonds across genders.

Overall, we show that similar to GPT4, GPT4o produces rating responses to financial survey questions that are highly correlated with real human responses, reflecting similar patterns across different demographic groups.

	Human direction	GPT4 direction	Agreement
old: bonds	+	+	✓
old: cash	+	+	✓
female: stocks	-	-	✓
female: bonds	-	+	×
high-income: stocks	+	+	✓
high-income: bonds	+	+	✓
high-income: cash	-	-	✓

TABLE D2: This table displays the relationship between ratings of the investment options (stocks, bonds, and cash) and demographic characteristics (age, gender, and income). We show the 7 correlations that are significant in both human response data and the GPT4o-generated data. A plus sign in the second and third columns means that the corresponding demographic is positively correlated with the rated asset. For example, the first row of this table shows that older individuals and simulated GPT4o agents both prefer keeping cash more than their younger counterparts.

D.2 Few-shot learning

We reanalyze our main results using another prompt variation, exploring a practical extension of our approach. Acquiring a large, up-to-date human survey dataset is costly and sometimes time-consuming; however, it is much easier to run a small pilot study to acquire a relatively small number of human samples. Here, we study whether we can use few-shot learning to incorporate a small human survey data set when asking GPT to generate more synthetic data.

Few-shot learning is a computer science technique used to query generative language models. In particular, we embed a few examples (few-shot) in the prompt when submitting the query (Brown et al., 2020). This is helpful when we want to inject domain knowledge into GPT on a subject that may be sparse in its training data, and it can be viewed as an alternative to fine-tuning – with a lower computational cost.

In our case, the few-shot prompts are of the following type:

> *Imagine you are an online survey participant. You will be asked to answer 6 questions about your opinion of investment options such as stocks and bonds. For the first three questions please only answer with one of the following options: very positive, somewhat positive, neutral, somewhat negative, very negative. For the last three questions, please answer with one of the four options: stocks, bonds, cash, or indifferent. Give your answers in the following format:*
>
> *Answer to question 1: the option you choose.*
>
> *Explanation: Five to ten words of explanation of your answer.*
>
> *Answer to question 2: the option you choose.*
>
> *Explanation: Five to ten words of explanation of your answer.*
>
> *Answer to question 3: the option you choose.*
>
> *Explanation: Five to ten words of explanation of your answer.*

Answer to question 4: the option you choose.

Explanation: Five to ten words of explanation of your answer.

Answer to question 5: the option you choose.

Explanation: Five to ten words of explanation of your answer.

Answer to question 6: the option you choose.

Explanation: Five to ten words of explanation of your answer.

Finally, report the age, gender, and gross annual income of your imagined identity. For example:

Age: XX.

Gender: XX.

Income: XX.

Human response example 1 (question-answer pairs).

Human response example 2 (question-answer pairs).

Human response example 3 (question-answer pairs).

Question 1: what are your views on investing in bonds?

Question 2: what are your views on investing in stocks?

Question 3: what are your views on investing in cash?

Question 4: which investment do you prefer? Stocks or cash?

Question 5: which investment do you prefer? Bonds or stocks?

Question 6: which investment do you prefer? Bonds or cash?

We use the following steps to conduct the analysis:

1. Randomly select 100 samples from the cleaned (outlier-removed) human survey responses.
2. Save the rest of the human data as testing data.
3. Subset the 100 randomly selected samples into 8 demographic groups defined in section 3.
4. Generate 150 responses using GPT4 for each demographic group:
    - Randomly choose 3 examples from the corresponding demographic subset without replacement.
    - Embed the examples in the prompt.
    - Query GPT4 and save the response.
5. Compare the responses generated by GPT4 using few-shot learning with the test human data set.

First, we reproduce the correlation table (table 1) with the few-shot learning data. As shown in table D3, the correlation coefficients are systematically higher than the ones without few-shot learning, except for stocks. In particular, when we pool together the ratings for stocks, bonds, and cash, the correlation coefficients are significantly higher when we use few-shot learning. Furthermore, the correlations' significance levels are improved for ratings on bonds, which are the lowest in table 1. All correlations using few-shot learning are positively significant at the 1% level.

	Pearson	**Spearman**	**Kendall**
All	0.808***	0.790***	0.645***
	(0.041)	(0.050)	(0.048)
Stocks	0.670***	0.738***	0.643***
	(0.126)	(0.164)	(0.142)
Bonds	0.761***	0.643***	0.429***
	(0.154)	(0.181)	(0.166)
Cash	0.908***	0.810***	0.643***
	(0.135)	(0.160)	(0.168)

TABLE D3: This table reports the Pearson, Spearman, and Kendall correlations between GPT4-generated responses using few-shot learning and human survey responses. These correlations are computed based on the average rating from each demographic group for the three investment options (pooled and separately). Bootstrapped (10,000 samples) standard errors are reported in parentheses.

Next, we check whether the results are more similar in terms of rating heterogeneity across demographic groups. More specifically, we replicate table 2 with few-shot learning data. As shown in table D4, all 7 coefficients significant in both datasets are directionally aligned: older individuals rate bonds and cash higher than younger ones, females rate stocks lower but cash higher than males, and high-income earners rate stocks and bonds higher while rating cash lower than their counterparts.

Overall, we observe that when we have a small number of real human survey responses, using few-shot learning can improve the correlation between the GPT4-generated ratings and real human ratings (out-of-sample) and better align the heterogeneity of ratings across demographic groups.

	Human direction	GPT4 direction	Agreement
old: bonds	+	+	✓
old: cash	+	+	✓
female: stocks	-	-	✓
female: cash	+	+	✓
high-income: stocks	+	+	✓
high-income: bonds	+	+	✓
high-income: cash	-	-	✓

TABLE D4: This table displays the relationship between ratings of the investment options (stocks, bonds, and cash) and demographic characteristics (age, gender, and income). We show the 7 correlations that are significant in both human response data and the GPT4-generated data with few-shot learning. A plus sign in the second and third columns means that the corresponding demographic is positively correlated with the rated asset. For example, the first row of this table shows that older individuals and simulated GPT4 agents both prefer keeping cash more than their younger counterparts.

D.3 Default GPT4 demographic group

In the main analysis, we specify a demographic group such as "female, below 39 years old, with an annual income below 54,000" each time we query GPT4. In this section, we study which demographic group GPT4 defaults to when no such information is provided in the prompt. More specifically, we use the following type of prompt to collect 150 responses from GPT4:

> *Imagine you are an online survey participant. You will be asked to answer 6 questions about your opinion of investment options such as stocks and bonds. For the first three questions please only answer with one of the following options: very positive, somewhat positive, neutral, somewhat negative, very negative. For the last three questions, please answer with one of the four options: stocks, bonds, cash, or indifferent. Give your answers in the following format:*
>
> *Answer to question 1: the option you choose.*
>
> *Explanation: Five to ten words of explanation of your answer.*
>
> *Answer to question 2: the option you choose.*
>
> *Explanation: Five to ten words of explanation of your answer.*
>
> *Answer to question 3: the option you choose.*
>
> *Explanation: Five to ten words of explanation of your answer.*
>
> *Answer to question 4: the option you choose.*
>
> *Explanation: Five to ten words of explanation of your answer.*
>
> *Answer to question 5: the option you choose.*
>
> *Explanation: Five to ten words of explanation of your answer.*

Answer to question 6: the option you choose.

Explanation: Five to ten words of explanation of your answer.

Finally, report the age, gender, and gross annual income of your imagined identity. For example:

Age: XX

Gender: XX

Income: XX.

Question 1: what are your views on investing in bonds?

Question 2: what are your views on investing in stocks?

Question 3: what are your views on investing in cash?

Question 4: which investment do you prefer? Stocks or cash?

Question 5: which investment do you prefer? Bonds or stocks?

Question 6: which investment do you prefer? Bonds or cash?

Looking at the self-reported demographics, 56% of GPT4 responses identify as female, all of them report above 54,000 annual income (high-income), and only 9 out of 150 report being at least 39 years old (old). Therefore, by default, most GPT4 agents self-identify as young and high-income individuals, while the gender dimension is relatively balanced.

Next, we look at the investment ratings and the human demographics with which they are most closely aligned. In particular, we construct a 3-dimensional Gaussian distribution for the ratings (stocks, bonds, and cash) from the responses of each human demographic group (eight groups based on gender, age, and income). Thus, we form eight distributions. For each GPT4 instantiation, we examine which of the eight distributions it is most likely to have been drawn from based on its generated investment ratings. We find that 0.667% of GPT4 agents are closest to the young, low-income, female group, 0.667% of GPT4 agents are closest to the old, high-income, female group, 28% of GPT4 agents are closest to the young, high-income, female group, 7.333% of GPT4 agents are closest to the old, low-income, male group, 8.667% of GPT4 agents are closest to the old, high-income, male group, and 54.667% of GPT4 agents are closest to the young, high-income, male group. Comparing the two sets of results, we observe that both GPT4 agents' self-reported demographics and ratings reveal that the default demographic group is likely young and high-income. However, while the self-reported demographics are relatively gender-balanced, generated *preferences* disproportionately reflect young high-income men.

E Supplemental discussions

E.1 Proof of proposition 1

Proposition:

Let $a \in \{\text{stocks}, \text{bonds}, \text{indifferent}\}$, $b \in \{\text{stocks}, \text{cash}, \text{indifferent}\}$, and $c \in \{\text{cash}, \text{bonds}, \text{indifferent}\}$ be the three responses provided by a survey participant to the three relative-preference questions. The participant's preference ordering satisfies transitivity if and only if the following conditions are met:

1. If $a, b, c \neq$ indifferent, exactly one of the following must be true $a = b$ or $b = c$ or $a = c$.

2. If $a =$ indifferent, then either $b = c$ or $b, c \in \{\text{stocks}, \text{bonds}\}$.

3. If $b =$ indifferent, then either $a = c$ or $a, c \in \{\text{cash}, \text{stocks}\}$.

4. If $c =$ indifferent, then either $a = b$ or $a, b \in \{\text{cash}, \text{bonds}\}$.

Proof:

We first show that when any of the conditions listed above are satisfied, we have a transitive preference relation.

When condition 1 is satisfied, without loss of generality, assume $a = b =$ stocks, we have stocks $\succ$ bonds and stocks $\succ$ cash. Therefore, depending on the preference relation between bonds and cash, we either have stocks $\succ$ cash $\succ$ bonds or stocks $\succ$ bonds $\succ$ cash. In both cases, the overall preference ordering is transitive.

When condition 2 is satisfied, if $b = c =$ indifferent, all three options are indifferent, and the preference relation is transitive. If $b = c =$ cash, the preference relation is cash $\succ$ stocks $\sim$ cash, which is also transitive. If $b =$ stocks and $c =$ bonds, the preference relation is stocks $\sim$ bonds $\succ$ cash, which is also transitive.

Conditions 3 and 4 are similar to condition 2, and any preference relation under either of these two conditions is also transitive.

Next, we show that if we have a transitive preference ordering among the three investment options, one of the conditions listed above must be satisfied.

First, assume there is no indifference in the preference relation, there must exist exactly one option that is strictly preferred over the other two. Therefore, we must have either $a = b$ or $b = c$ or $a = c$.

Then, assuming there is only one indifference in the preference relation, the two options that are indifferent must either be strictly preferred over the third option or strictly less preferred than the third option. If they are both preferred over the third option, we have either $b =$ stocks and $c =$ bonds (when $a =$ indifferent), $a =$ stocks and $c =$ cash (when $b =$ indifferent), or $a =$ bonds and $b =$ cash (when $c =$ indifferent). If the third option is preferred over both of the indifferent options, we have either $b = c =$ cash

(when a = indifferent), $a = c$ = bonds (when b = indifferent), or $a = b$ = stocks (when c = indifferent).

E.2 Introduction to neural networks

We start by discussing a simple neural network: a one-hidden-layer linear neural network.[15] This network is defined by three dimensions: input dimension $\dim_{in}$, hidden dimension $\dim_h$, and output dimension $\dim_{out}$.

There are two mappings in this one hidden layer network. The first is the mapping from the input space to the hidden space. Mathematically, let the input data be X

$$H = f_1(X) = XW_1 + B_1,$$

. Then the hidden space H can be represented as where W_1 and B_1 are trainable matrices of parameters.

The second function maps from the hidden space H to the output space Y:

$$Y = f_2(H) = f_2(f_1(X)) = (XW_1 + B_1)W_2 + B_2,$$

$$= XW_1W_2 + B_1W_2 + B_2,$$

where W_2 and B_2 are trainable matrices of parameters.

[15] This introduction of neural networks and the self-attention mechanism are based on the discussion in Hochberg et al. (2023).

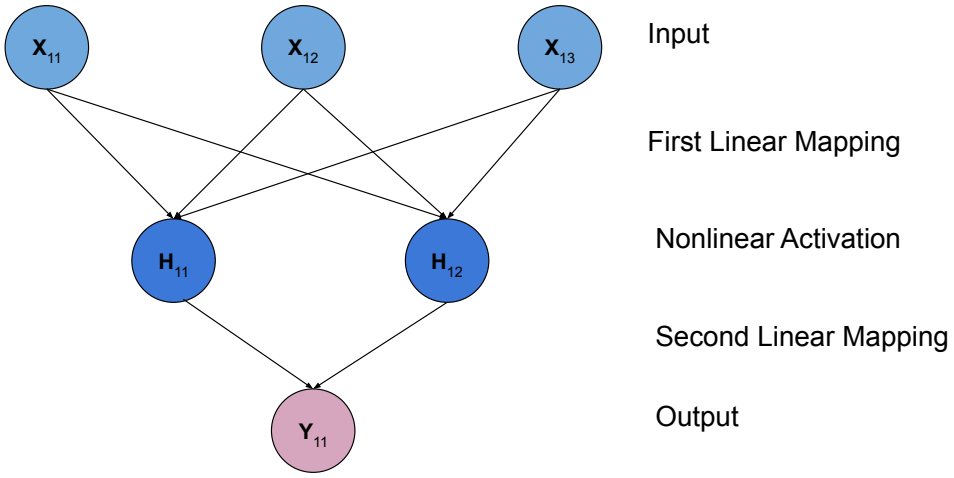


Figure E1: Diagram of a one-hidden-layer neural network with a nonlinear activation function. The top blue circles are the inputs, which, in the case of this figure, are three-dimensional vectors. The green circles in the middle are the nodes in the hidden layer, and the violet circle on the bottom is the output.

As shown in Figure E1, this simple linear network can be generalized by adding a nonlinear activation function $g(\cdot)$. When we apply the activation function to the first mapping, the output of the first mapping (the hidden space) becomes

$$H = g(f_1(X)) = g(XW_1 + B_1).$$

Similarly, we can apply a nonlinear activation function after any mapping to add nonlinearity to a linear transformation, allowing neural networks to more flexibly fit any relation between the input X and output Y.

E.3 Introduction to GPT4

In this section, we introduce the different components of GPT4. We first introduce the decoder architecture, which is a superset of models that include the GPT family, and then we introduce the self-attention mechanism which allows GPT4 to be aware of context when generating new words. Next, we discuss the pre-training steps of the base model of GPT4, and lastly, we describe the improvement of GPT4 (and 3.5) compared to earlier GPT models.

E.3.1 Decoder

The original Transformer architecture was designed for tasks such as machine translation, employing both an encoder and a decoder. In the example of a transformer-based translation algorithm, the encoder produces a numerical representation of the input up to token $t+1$ where the $(t+1)$th token is the next one to be translated, and the decoder takes the encoder's output and a numerical representation of the t words that have been translated so far to predict the translation of the $(t+1)$th word. However, GPT uses a variant of the Transformer architecture with only the decoder component. This means it focuses solely on a numerical presentation of the text that has been generated and tries to predict the next token, making it suitable for tasks like text completion and text generation.

The decoder contains four major components: positional encoding, self-attention layers, position-wise feed-forward networks, and layer normalization and residual connections. We briefly describe each of them and then elaborate on the self-attention layer because it is the main driving force of the model.

In the architecture of Generative Pre-trained Transformer (GPT) models, positional encoding is a critical component that provides information about the position of tokens in a sequence. Since the Transformer architecture does not inherently consider the order of tokens, positional encoding helps the model distinguish between tokens based on their position.

Positional encoding involves adding fixed-length vectors to the input embeddings of tokens before feeding them into the model. These positional embeddings encode information about the position of each token relative to others in the sequence. GPT uses sinusoidal functions to produce positional embeddings.

$$\begin{aligned} \mathrm{PE}_{(pos,2i)} &= \sin\left(\frac{pos}{10000^{2i/d_{\text{model}}}}\right) \\ \mathrm{PE}_{(pos,2i+1)} &= \cos\left(\frac{pos}{10000^{2i/d_{\text{model}}}}\right), \end{aligned}$$

where $\mathrm{PE}_{(pos,2i)}$ are the positional embeddings of tokens at even positions, $\mathrm{PE}_{(pos,2i+1)}$ are the positional embeddings of tokens at odd positions, and d_{model} is the dimensionality of the embeddings (1,536-dimensional for GPT)

The positional encoding vectors are added to the input embeddings of tokens, injecting positional information into the model's input representation. By incorporating positional encoding, GPT ensures that the model can differentiate between tokens based on their position, allowing it to capture sequential dependencies effectively.

In addition, the decoder comprises multiple layers of self-attention mechanisms. Each layer processes the input sequence independently and captures dependencies within the sequence. The self-attention mechanism allows the model to assign different weights to each token based on its relevance to other tokens in the sequence, enabling it to understand the context and generate text accordingly.

Following the self-attention layers, each position in the sequence passes through a position-wise feedforward neural network. This network consists of multiple fully connected layers with non-linear activation functions, enabling the model to capture complex patterns in the data. The position-wise feedforward networks help refine the representation of each token in the sequence, incorporating both local and global context information.

Furthermore, to stabilize training and facilitate the flow of gradients, GPT incorporates layer normalization and residual connections after each self-attention layer and position-wise feedforward network. Layer normalization normalizes the activations of each layer, reducing internal covariate shifts and improving the training stability. Residual connections allow gradients to flow directly through the network, mitigating the vanishing or exploding gradient problem commonly encountered in deep neural networks.

E.3.2 Self-attention

The goal of self-attention is to create a numerical embedding for each piece of text, respecting each token's contextual relation with all of the tokens in the text. More specifically, the raw input to the attention mechanism is a piece of text T. Then the text is broken into sub-word tokens in a parsing process called tokenization. This set of tokens is predefined such that a relatively limited number of tokens can be combined to represent a large amount of unique words. For example, the prefix "un" is a token in many models because it has the meaning of negation when combined with many other sub-word tokens, such as "happy." Many other tokens capture short and common words such as "and."

After tokenization, each token is assigned a naive embedding that combines a representation of the meaning of the word and the position of the word in the whole text. The result is a set of naive embeddings

$$\text{EMB}_0 = [[\text{BOS}], t_1, ..., t_N, [\text{EOS}]]$$

where t_i is the embeddings for token i, "[BOS]" (beginning of sentence) is a special token that is used to denote the start of a sentence, and "[EOS]" (ending of sentence) is a special token denoting the end of a sentence.

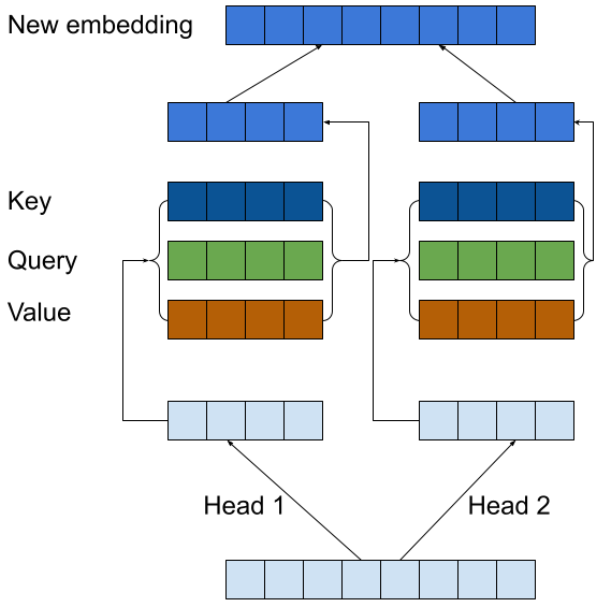


Figure E2: Diagram of a multi-head attention layer

As shown in Figure E2, a multi-head self-attention layer takes in an embedding and outputs another embedding. The input embedding is passed through three linear mappings in parallel to form three matrices: the key matrix, the query matrix, and the value matrix.

$$Q = \text{EMB}_0 W^Q$$

$$K = \text{EMB}_0 W^K$$

$$V = \text{EMB}_0 W^V$$

where Q, K, and V are trainable parameter matrices. Then for each query, a cosine similarity score is computed between this query and all of the keys, including itself. Next, the value of the token is represented as a linear combination of all of the values of tokens in this piece of text. The weights in the linear combination are the cosine similarities between queries and keys. Mathematically, we have

$$\text{Attention}(\text{EMB}_0) = \text{softmax}(QK^T)V$$

For GPT models specifically, the attention is often calculated as

$$\text{Attention}(\text{EMB}_0) = \text{softmax}\left(\frac{QK^T}{\sqrt{d_k}}\right)V$$

where d_k is a scaling factor equal to the number of columns of K. To improve representation capacity, the input embeddings EMB_0 are often broken into several sub-vectors of equal size. The attention is computed for each sub-vector independently and concatenated to output a multi-head attention of the input embedding. In addition, this attention procedure is often repeated many times where the output of the $(i-1)$th attention is normalized and combined with the input of the $(i-1)$th attention to act as the input to the ith attention. In the case of GPT4, each embedding is 1,536-dimensional.

E.3.3 Pre-training

GPT is trained on the autoregressive language modeling task. Autoregressive language modeling revolves around predicting the next token in a sequence given its preceding context. Mathematically, this can be represented as maximizing the log-likelihood of observing the next token x_{i+1} given the preceding tokens $x_1, x_2, ..., x_i$ and the model parameters θ. This can be formulated as:

$$\mathcal{L}_{\text{pretrain}}(\theta) = \sum_{i=1}^{n-1} \log P(x_{i+1}|x_1, x_2, ..., x_i; \theta)$$

where $\mathcal{L}_{\text{pretrain}}(\theta)$ is the training objective, and θ represents the parameters of the model.

In essence, the autoregressive language modeling objective encourages the model to capture the intricate patterns and dependencies present in the language. By learning to predict the next token based on its context, GPT effectively internalizes syntactic and semantic structures, learning to generate text that adheres to grammatical rules and maintains coherence. Moreover, the autoregressive nature of the training procedure inherently encourages the model to capture long-range dependencies in text, ensuring that it can contextualize information across a wide span of tokens.

Through backpropagation and gradient descent, the model learns to adjust its parameters to minimize the negative log-likelihood of observing the next token in the sequence and gradually enhances its ability to capture nuanced linguistic patterns and generate text that is coherent and contextually appropriate. The following list shows some of the sources used to conduct pretraining for the base model for GPT4:

1. **Common Crawl**: A vast dataset containing web pages collected from the Internet, providing a wide variety of text data.

2. **Wikipedia**: Wikipedia articles from various languages and domains, offering structured and comprehensive information across a multitude of themes.

3. **BooksCorpus**: A collection of books covering different genres and authors, allowing the model to learn from literary works and fictional narratives.

E.3.4 Reinforcement Learning with Human Feedback (RLHF)

GPT4 leverages reinforcement learning with human feedback to improve its text-generation capabilities. In this framework, GPT4 generates text samples, and these samples are then evaluated by human judges or annotators. The human feedback serves as a reward signal for the model.

Formally, let S represent the set of all possible text samples that GPT4 can generate. The model generates text samples according to its current policy π_θ, parameterized by θ. Each generated sample $s \in S$ is evaluated by human judges, yielding a feedback signal $r(s)$, where $r(s)$ indicates the desirability of the generated text (trained from human feedback).

The goal of GPT4 is to learn an optimal policy π_θ that maximizes the expected cumulative reward over the distribution of text samples. This can be formulated as the following optimization problem:

$$\max_\theta \mathbb{E}_{s\sim\pi_\theta}[r(s)]$$

where $\mathbb{E}_{s\sim\pi_\theta}[r(s)]$ represents the expected reward over the distribution of text samples generated by the model.

To optimize the policy, GPT4 employs a policy gradient method to update the model's parameters θ based on the received human feedback, aiming to increase the likelihood of generating high-quality text samples in the future.

Overall, reinforcement learning with human feedback enables GPT4 to iteratively improve its text generation capabilities by learning from the evaluations of human judges.

E.4 Definition of correlation coefficients

- **Pearson Correlation Coefficient**

  Formula:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}.$$

  The Pearson correlation coefficient measures the linear relationship between two

continuous variables. The formula calculates the covariance of the variables normalized by the product of their standard deviations. The correlation coefficient r_{xy} ranges from -1 to 1, where $r = 1$ indicates a perfect positive correlation, $r = -1$ indicates a perfect negative correlation, and $r = 0$ indicates no correlation. When r is close to 1 or -1, it suggests a strong correlation between the variables.

- **Spearman's Correlation Coefficient**

  Formula:

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}.$$

  Spearman's rank correlation coefficient assesses the monotonicity of the relationship between two variables. The formula computes the differences between the ranks of corresponding data points, squares them, sums them up, and normalizes the result. The coefficient ρ ranges from -1 to 1, where $\rho = 1$ indicates a perfect positive correlation, $\rho = -1$ indicates a perfect negative correlation, and $\rho = 0$ indicates no correlation.

- **Kendall's Correlation Coefficient**

  Formula:

$$\tau = \frac{(\text{number of concordant pairs}) - (\text{number of discordant pairs})}{\frac{1}{2}n(n-1)}.$$

  Similar to Spearman's coefficient, Kendall's correlation coefficient also evaluates the ordinal (rank) association between two variables. It counts the number of concordant and discordant pairs of observations and normalizes them. A concordant pair refers to a pair of observations where the ranks are in the same order for both variables. That is, if in the first variable, X has a higher rank than Y, and in the second variable, X also has a higher rank than Y, then this pair is considered concordant. A discordant pair is the opposite. The coefficient τ ranges from -1 to 1, where $\tau = 1$ indicates perfect agreement between the rankings, $\tau = -1$ indicates perfect disagreement between the rankings, and $\tau = 0$ indicates no association between the rankings.

F Analysis of explanations of cash and bonds ratings

In this section, we use GPT4 to extract themes beyond risk and return in the explanations of ratings of cash and bonds, analogous to the analysis conducted in Section 4.3 for stocks. We leverage GPT4's summarization capabilities to extract five themes that differentiate explanations of positive ratings (> 3) versus negative ratings (< 3). For each asset class, we repeat this process three times and consider themes that consistently appear across different runs of the summarization procedure.

F.1 Investing in bonds

The major common theme discovered in explanations of bond ratings is the level of "knowledge" and understanding of financial markets (i.e., financial literacy). Similar to Section 4.3, we use the difference between the embeddings of the following two sentences as the axis which represents the level of knowledge about the bond market:

- I am very knowledgeable about the bond market.
- I do not know anything about the bond market.

As shown in Figure F1, the distributions of the embeddings of human and GPT4-generated responses both have three humps. Therefore, we use a mixture of three Gaussian distributions to cluster the responses. The human distribution contains two negative clusters (centered at -0.05 and -0.02) and one mildly positive cluster (centered at 0.01). The GPT4 distribution contains one negative cluster (centered at -0.02), one neutral cluster (centered at -0.004), and one positive cluster (centered at 0.01).

Table F1 shows the demographic variations associated with differences in agents' knowledge about the bond market. Older, male, and higher-income human participants tend to be more knowledgeable about the bond market (significant at the 5% level). Similarly, older and higher-income GPT4 agents have a better understanding of the bond market. The one disagreement between data generated by GPT4 and actual human survey data is the role of gender: while human men express significantly more knowledge about the bond market than women, simulated GPT4 agents tend to express greater knowledge about the bonds market when they are female, although this difference is only marginally significant (at the 10% level).

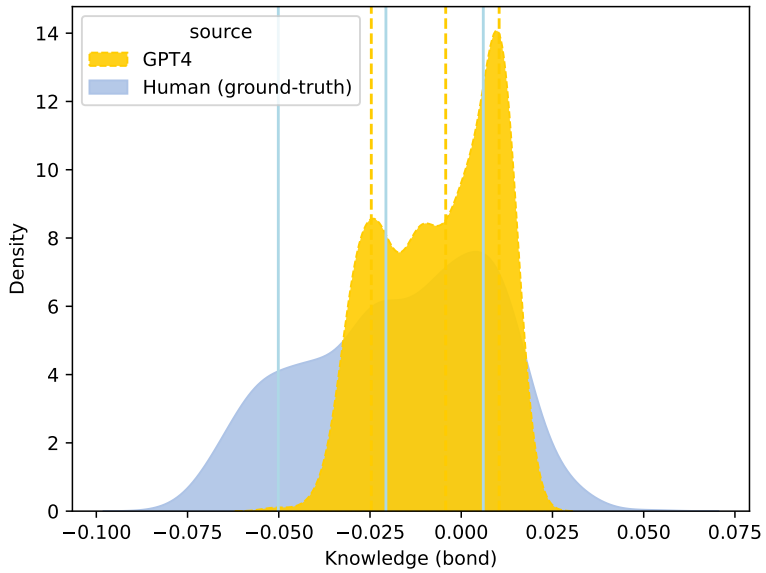


Figure F1: The density of human and GPT4-generated responses' relevance to having a high amount of knowledge about the bond market. The blue density plot represents the human data, and the yellow plot represents the GPT4-generated data. The continuous vertical lines mark the centers of the three clusters of human responses, and the dotted vertical lines represent the centers of the three clusters of GPT4-generated data.

F.2 Keeping cash

Next, we analyze the themes of the explanations corresponding to positive versus negative attitudes toward holding cash. We find that the most consistent theme in these responses other than risk and return is "accessibility," or the convenience of holding cash, including its liquidity. Some individuals rate cash highly because it is readily accessible at any time. We construct the accessibility dimension using the following sentences:

- I like the high level of accessibility of cash.
- I do not care about the level of accessibility of cash.

As shown in figure F2, the distributions of the embeddings of human and GPT4 explanations both have two humps. Therefore, we use a mixture of two Gaussian distributions to cluster the responses. The human distribution contains one positive cluster (centered at 0.04) and one nearly neutral cluster (centered at 0.0002 and containing 58% of the participants). The GPT4 distribution also contains one positive cluster (centered at 0.05) and one nearly neutral cluster (centered at 0.02 and containing 79% of the simulated GPT4 agents).

	Dependent variable:	
	Knowledge about the bond market (cluster label)	
	Human	GPT4
age	0.004**	0.011***
	(0.002)	(0.004)
gender	−0.269***	0.087*
	(0.048)	(0.048)
income	0.003***	0.041***
	(0.001)	(0.006)
Observations	1,074	1,042
R^2	0.054	0.058
Adjusted R^2	0.051	0.055
Residual Std. Error	0.791 (df = 1070)	0.768 (df = 1038)
F Statistic	20.391*** (df = 3; 1070)	21.118*** (df = 3; 1038)
Note:		*p<0.1; **p<0.05; ***p<0.01

TABLE F1: This table shows the correlations between age, gender, and income and human participants' (GPT4 agents') knowledge about the bond market. Income is scaled in thousands of dollars.

Table F2 shows the demographic variations associated with differences in agents' level of consideration of the high accessibility of cash. Older and lower-income GPT4 agents care more about the high accessibility of cash. However, human participants do not show strong demographic differences in terms of the importance assigned to the accessibility of cash.

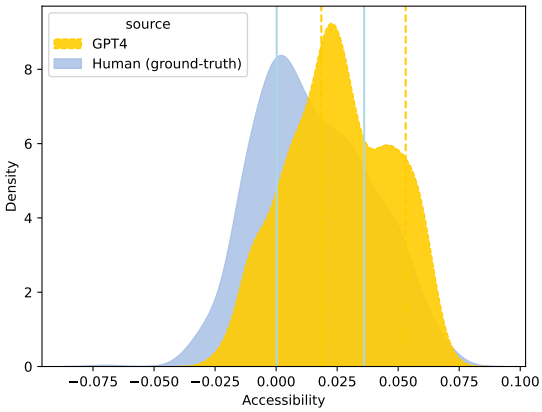


Figure F2: The density of the relevance of human and GPT4-generated explanations of cash ratings to caring about the high accessibility of cash. The blue density plot represents the human data, and the yellow plot represents the GPT4-generated data. The continuous vertical lines mark the centers of the two clusters of human responses, and the dotted vertical lines represent the centers of the two clusters of GPT4-generated data.

	Dependent variable:	
	Caring about the accessibility of cash (cluster label)	
	Human	GPT4
age	0.001	0.007***
	(0.001)	(0.002)
gender	−0.010	0.039
	(0.030)	(0.026)
income	−0.00004	−0.022***
	(0.0004)	(0.003)
Observations	1,074	1,042
R^2	0.001	0.056
Adjusted R^2	−0.002	0.053
Residual Std. Error	0.492 (df = 1070)	0.406 (df = 1038)
F Statistic	0.432 (df = 3; 1070)	20.364*** (df = 3; 1038)
Note:		*p<0.1; **p<0.05; ***p<0.01

TABLE F2: This table shows the correlations between age, gender, and income and human participants' (GPT4 agents') level of consideration of the high accessibility of cash. Income is scaled in thousands of dollars.