Do Individuals Have Preferences Used in Macro-Finance Models? An Experimental Investigation*

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Abstract

Recent financial studies often assume agents have Epstein and Zin (1989) preferences, preferences which require agents to care about when uncertainty is resolved. Under this "recursive-preference" framework, the preference for uncertainty resolution is entirely determined by an agent's preferences for risk and intertemporal substitution. To test the implications of this model, this paper presents an experiment designed to elicit subject preferences on risk, time, intertemporal substitution, and uncertainty resolution. Results reveal that most subjects prefer early resolution of uncertainty and have relative risk aversion greater than the reciprocal of the elasticity of intertemporal substitution, consistent with the predictions by recursive preferences. After classifying subjects in a finite mixture model by their risk, time and intertemporal-substitution parameters, regression results show that types predicted by Epstein-Zin to prefer early resolution choose early resolution with 20–50% higher probability.

JEL: G11, C91, G12, D53

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1 Introduction

In making economic decisions, agents take into account attitudes toward risk, the flexibility of substituting current consumption for future consumption, and the speed of uncertainty resolution. However, the traditional model of decision-making under risk, expected utility theory (von Neumann and Morgenstern, 1944; Bernoulli, 1954), neglects the idea that economic agents may have a preference as to when uncertainty is resolved. Agents are assumed to be indifferent about the timing of uncertainty resolution. To some, this assumption may feel unintuitive; one can think of many cases where an individual would like to know the results of uncertainty either immediately or at a later time.[1] Furthermore, it is well known that the assumption of indifference, when applied to macroeconomic and financial data, can lead to various asset pricing anomalies.[2]

More sophisticated models (Kreps and Porteus, 1978; Epstein and Zin, 1989; Weil, 1990) allow agents to have a preference for uncertainty resolution, and agents' risk and intertemporal-substitution parameters are separately determined.[3] The added flexibility of a preference for timing of uncertainty resolution proves useful in finance. Epstein and Zin (1991) and Campbell (1993) offer some early empirical work employing this recursive preference. Recently, Bansal and Yaron (2004), Hansen et al. (2008) and Kim et al. (2009) and many others use these preferences to explain a number of financial anomalies.[4]

With such flexible recursive preferences, risk aversion, elasticity of intertemporal substitution, and preferences on uncertainty resolution are associated with each other under mild conditions. In particular, if an agent is more risk averse or more susceptible to changes in interest rate, faster resolution of uncertainty

[1]An economic agent that wishes to plan his consumption would be much better off knowing what his future income will be. This implies that early resolution of uncertainty is generally preferred. However, this planning motive may state otherwise. For instance, if the current volatility of income is high and the stochastic volatility is mean reverting, the agent may want to delay his decisions until this short-term volatility is winding down. A similar, yet behavioral explanation is that delay induces decision makers to be less risk-averse (Ebert and Prelec, 2007; Baucells and Heukamp, 2012). Even when it will not affect his decisions, the agent may wish to know his future income early to reduce anxiety (Wu, 1999; Epstein, 2008) or satisfy curiosity (Loewenstein, 1994; Kang et al., 2009). Alternatively he may wish to wait to learn his future income to preserve hope (Chew and Ho, 1994; Caplin and Leahy, 2001; Epstein, 2008).

[2]These include the equity premium, volatility and interest rate puzzles, following Hansen and Singleton (1982), Mehra and Prescott (1985), and Weil (1990). Simply put, key parameter describing relative risk aversion, i.e., the inverse of the elasticity of intertemporal substitution is estimated too big (around 150–200) to match the first and second moments of stock and bond returns. This led many researchers to look for preference specifications consistent with both macro and finance data. Although there are some production-based models that use the power utility function tackling these anomalies, such as Gomes et al. (2003), those generate additional counterfactual results in fitting the moments of key macroeconomic and financial variables.

[3]Related, there are several theoretical studies attempting to link the decision margins of time and risk in an interactive way. While the attitudes towards temporal resolution are mostly analyzed in conjunction with risk (e.g., Grant et al., 1998, 2000; Epper and Fehr-Duda, 2012), Strzalecki (forthcoming) analyzes the association between ambiguity aversion and the temporal resolution of uncertainty. Coble and Lusk (2010) elicit risk and time preference and estimate uncertainty-resolution preference through model calibration.

[4]Bansal and Yaron (2004) exploit this aspect to explain equity premium puzzle together with a time-varying, conditional mean component. Kim et al. (2009) develop a stochastic volatility model with two asymptotic regimes and smooth transitions and show that this preference for uncertainty resolution can explain aversion to uncertainties in regimes, and thereby many asset pricing puzzles. Related, incorporating ambiguity aversion into the recursive preferences continues to be an important research agenda nowadays. See Jeong et al. (2009) for its empirical analysis, and Epstein and Schneider (2010) for an excellent review on the ambiguity aversion and Epstein-Zin preferences.

would be preferred.[5] Given the testable implications of the recursive preferences and the current popularity in the literature, eliciting the key parameters can shed light on the relevance of this preference function and the related implications. However, there have been few attempts to study this issue experimentally in an integrated setting, and this paper attempts to fill this important gap in the literature.

This paper uses choice menus (Cohen et al., 1987) to elicit risk, time, and elasticity of intertemporal substitution preferences from subjects. It then examines whether subjects' parameters for risk and intertemporal substitution and their preferences for uncertainty resolution are consistent with the relevant results from the Epstein-Zin model. The results from a finite mixture model estimation show that roughly two thirds of subjects best fit a type that has relative risk aversion (RRA) greater than the inverse of the elasticity of intertemporal substitution (EIS), or risk parameter (α) less than intertemporal-substitution parameter (ρ). The remainder best fit a traditional expected utility type with $\rho = \alpha$. Under Epstein-Zin preferences, these results imply that most subjects should prefer early resolution of uncertainty. A majority of the subjects (60.4 percent) do demonstrate a preference for early resolution, about one third are indifferent (36.6 percent), and three percent exhibit a preference for late resolution. Further, regression analysis suggests subjects fully classified as $\alpha < \rho$ types in the finite mixture model have a 20–50% higher probability of choosing early resolution in the experiment than types fully classified as $\alpha = \rho$.

Admittedly, this is not the first experimental investigation into preferences over uncertainty resolution. Several papers elicit subject values for a variety of reasons, using different parametric models, and they have not reached a consensus.[6] Among those, Benzion et al. (1989), Ahlbrecht and Weber (1997), and von Gaudecker et al. (2011) look at *some* (though not *all*) of the interrelations between uncertainty resolution and risk preference.[7] Benzion et al. (1989) experimentally study if discount rates of subjects vary when decisions are expedited or delayed. Ahlbrecht and Weber (1997) survey subjects about their preference for gradual uncertainty resolution over time to test the Kreps-Porteus model, but do not compare them to elicited parameter values. The closest design to this experimental approach, von Gaudecker et al. (2011), elicit subject preferences related to risk aversion, loss aversion, and uncertainty resolution. In a field experimental setting, they build a structural model that estimates risk, based on an exponential utility function. However, they do not analyze intertemporal substitution, hence they ignore the relationships among the key preference parameters dictated by recursive preferences. In addition, they find the preference over uncertainty resolution to be the parameter least important in determining risk preferences, which is opposite to the results presented in this paper and the related macro-finance literature.

Unlike the aforementioned papers, this paper elicits preferences specifically to test the main theoretical implication of Epstein and Zin (1989), a predominant model in macroeconomics and finance studies. The previous studies did not intend to test this implication; nor did they gather the relevant data to pursue this question. Thus, the purposes and results of this paper are unique and have clear relevance to the finance

[5] Epstein and Zin (1989) show this in a parametric setup, and this paper further generalizes this finding.

[6] See Chew and Ho (1994); Ahlbrecht and Weber (1997); Eliaz and Schotter (2010); Erev and Haruvy (2010); van Winden et al. (2011); Abdellaoui et al. (2011); von Gaudecker et al. (2011).

[7] Related, Barksy et al. (1997) report results on risk aversion, time preference, and intertemporal substitution using survey data. However, they do not link these to temporal resolution of uncertainty.

literature.

To this end, the paper further illustrates the value of laboratory experiments into the financial economist's standard toolkit. By studying the interrelationship between the key aspects of dynamic and stochastic preferences of individuals—which are vital to understand the behaviors of financial and economic decision makers and resultant asset markets—it is a novel addition to a class of burgeoning literature that experimentally studies links between non-standard preferences and financial behaviors (e.g., Gneezy et al., 2003; Kluger and Wyatt, 2004; Bossaerts and Plott, 2004; Klos et al., 2005; Bossaerts et al., 2007, 2010; Ahn et al., 2011).

The paper proceeds as follows: Section 2 explains the theoretical underpinnings of the experiment and compares the predictions of the Epstein-Zin model with those of expected utility preferences with a power utility function; Section 3 describes the design of the experiment; Section 4 examines the predictions of the Epstein-Zin model to this specific environment; Section 5 reports the results of the experiments; and Section 6 concludes with a discussion on the implications on asset allocation decisions when decision makers have preferences similar to those found in this experiment.

2 Theoretical background

This section explains theoretical relations between the attitudes toward risk, intertemporal substitution, and uncertainty resolution. Based on Kreps and Porteus (1978) and Epstein and Zin (1989), a generalized result on the connections across time, risk, and uncertainty is presented.[8] Suppose that the preferences of economic agents are given as

$$V_t = F\left[C_t, h^{-1}\left(E_t h\left(V_{t+1}\right)\right)\right] \tag{1}$$

where F is an increasing, concave function called an aggregator following Koopmans (1960), and h is another increasing, concave function such that $h^{-1}Eh(\cdot)$ is the certainty equivalent for the future utilities denoted as μ. Following Kreps and Porteus (1978), a composite function of V, U is computed as

$$\begin{aligned} U(C,\mu) &= h(V) \\ &= h\left(F[C_t,\mu]\right) \end{aligned} \tag{2}$$

where U is a composite function defined as $h \circ F$. It is easy to infer that U is increasing and concave. Now, assuming that U is a homothetic function, the coefficients of relative risk aversion (RRA) and elasticity of intertemporal substitution (EIS) are written as follows:

$$RRA = -\frac{h''(\mu)\mu}{h'(\mu)}, \tag{3}$$

$$EIS = \frac{\partial \log\left(\frac{\mu}{c}\right)}{\partial \log(IMRS)} = \frac{U_1(C,\mu)}{\mu\left(U_{12}(C,\mu) - U_1(C,\mu)\frac{U_{22}(C,\mu)}{U_2(C,\mu)}\right)}, \tag{4}$$

[8]This general result assures that interactions among different aspects of time and risk preferences do not result from particular parametric forms, which will be discussed in detail later.

where h', h'' are the first and second derivatives of the h function respectively, $U_i, U_{ij}, i, j = 1, 2$ are the first and second derivatives of the U function with respect to each of the two arguments, and $IMRS$ refers to the intertemporal marginal rate of substitution. RRA is defined following Arrow (1971) and Pratt (1964), while EIS is derived using Kihlstrom and Mirman (1974). From the increasing property and concavity of $h(\cdot)$, RRA defined as (3) is positive, implying that there is risk aversion. Regarding intertemporal substitution, (4) states that the first and second derivatives of the composite function U jointly determine how readily decision makers substitute between current and future consumptions. Since RRA is defined on static gambles, while preferences on temporal uncertainty concern dynamic lotteries, the curvature of the preference function on the future utilities will likely be relevant in considering the attitudes toward dynamic uncertainty. The following theorem formalizes this intuition.

Theorem 1 (Kreps and Porteus)**.** *Denote $Eh(U)$ by x in* (1)*, and define $u(C, x) = U\left(C, h^{-1}(x)\right)$. Then, early (late) resolution of uncertainty is preferred if and only if $u(C, x)$ is convex (concave) in x. If $u(C, x)$ is affine in x, the decision maker is indifferent to the timing of uncertainty resolution.*

Proof. See the proof of Theorem 3 in Kreps and Porteus (1978). □

As expected, the theorem states that the preferences toward the uncertainty resolution over time will be associated with the curvature of an aggregator function U with respect to a concave function h of future utilities. That is, it is inferred that preference on uncertainty resolution is associated with measuring risk aversion to dynamic lotteries. To gain further insight on the link to other preferences, the following can be shown:

Theorem 2. *A decision maker prefers early (late) resolution of uncertainty if and only if*

$$RRA > (<) \frac{1}{EIS} - \mu \frac{U_{12}}{U_1}. \tag{5}$$

Proof. To apply the result from Theorem 1, the second derivative of the function u with respect to x is computed as

$$\frac{\partial^2 u(C, x)}{\partial x^2} = \frac{U_{22} - U_2 \frac{h''}{h'}}{(h')^2}.$$

Then, the sign of the numerator of this differential determines the preferences over temporal resolution of uncertainty. Using (3) and (4) to rewrite the numerator in terms of RRA and EIS, the result is obtained. □

Thus, the theorem reveals a close interrelationship between risk aversion, intertemporal substitution, and the temporal resolution of uncertainty. Specifically, higher risk aversion or higher intertemporal substitution implies early resolution of uncertainty up to the sign of U_{12}. The result is intuitively appealing. If a decision maker is highly risk averse and very keen on shifting resources between present and future, early resolution of uncertainty can be beneficial to make dynamic choices, because the decision maker can readily allocate income to the future in which uncertainty is resolved.

Interestingly, our experimental results, which will be explained later in detail, state that most subjects are risk averse since they choose the safe option even when it has a lower expected value. In addition, many subjects do not switch from a sure payoff to some combinations of money today and in one week, and therefore, for a large portion of subjects their choices are consistent with low preferences for income smoothing. Consistent with Theorem 2, it turns out that the majority of subjects prefer early resolution of uncertainty. This sheds light on the main implication of Theorem 2 without a specific parametric preference function.

Theorem 2 generalizes the condition in Epstein and Zin (1989) with a case of a constant elasticity of substitution (CES) aggregator for the function F in (1). In particular, Epstein and Zin (1989) and Weil (1990) assume that the individual has recursive preferences with the value V as

$$V_t = \left[(1-\beta)C_t^{\rho} + \beta\left(E_t V_{t+1}^{\alpha}\right)^{\frac{\rho}{\alpha}}\right]^{\frac{1}{\rho}}, \tag{6}$$

where C is the consumption of this individual, β is the time preference parameter, the elasticity of intertemporal substitution is $1/(1-\rho)$, and relative risk aversion is $(1-\alpha)$. Applying Theorem 2 to this setup yields the following well-known result.

Corollary 1 (Epstein and Zin)**.** *Early (late) resolution is preferred if $\alpha < \rho$ $(\alpha > \rho)$, and indifference towards timing of uncertainty if $\alpha = \rho$.*

Proof. Note that $h(x) = x^{\alpha}$ and $U = V^{\alpha}$. Similar to the proof of Theorem 2, $u(C, x)$ is convex (concave) with respect to the second argument x if

$$U_{22} - U_2\frac{h''}{h'} = U_2(\rho-\alpha)\left(1 - \frac{\beta\mu^{\rho}}{C^{\rho}+\beta\mu^{\rho}}\right) > (<)0.$$

Since $U_2 > 0$ and $1 - \frac{\beta\mu^{\rho}}{C^{\rho}+\beta\mu^{\rho}} > 0$ hold, $\rho - \alpha > (<)0$ is associated with the early (late) resolution of uncertainty. With $\rho = \alpha$, indifference prevails. $\square$

If an experimental design elicits these aspects of preferences under a dynamic and stochastic situation, this will provide an examination of the theoretical restrictions on these different aspects of preferences. It is worth mentioning that investigating these preferences *jointly* is critical to understand the recursive preferences due to the interrelation of uncertainty resolution, risk aversion, and intertemporal substitution. The next section accounts for the design in detail. For the purpose of evaluating these restrictions given by Theorem 2, the parametric form (6) is used, though the main insight of Theorem 2 carries over regardless of functional form.

3 Experimental design

This experiment used choice menus (Cohen et al., 1987) to elicit subject preferences over risk, time, and intertemporal substitution. To elicit preferences over the resolution of uncertainty, subjects were asked about a possible payment of \$20 two weeks in the future, determined by the roll of a die. Subjects chose whether to roll the die today or one week later.

Subjects were 101 undergraduates from Texas A&M University from varying majors. They participated in two experimental sessions exactly one week apart. Ninety-four subjects (93%) returned for their follow-up sessions. The first session lasted one hour; the second session lasted 30 minutes. Subjects earned $28.01 on average, including a $20 bonus if they attended both sessions.[9] The bonus was purposely very large to induce nearly all subjects to return to the experiment. If a large portion of subjects skipped the second session, a subject's preference to learn the results of a lottery early (see section 3.4), might only be due to a strategic decision to skip the second session if the lottery resolves unfavorably. Sessions took place at the Experimental Research Laboratory at Texas A&M University during April, May, and June 2009 and September 2010.

Subjects were undergraduates solicited from the Texas A&M University internet-based database, econ-dollars.tamu.edu, based on ORSEE (Greiner, 2004). They were instructed during recruitment to be available for an additional session one week later, and that failing to attend the second session would result in a loss of experimental earnings.

Once the experiment began, subjects received paper copies of their instructions. The experimenter read subjects the instructions and explained all the conditions of the experiment.[10] Subjects would make 61 binary choice decisions involving monetary payments over different time intervals. After making these decisions, subjects would roll dice to determine which of their choices would be selected. Subjects would be paid their preferred choice in the time horizon specified.

The experiment consisted of four tasks. The first three tasks featured two parts each; they were the risk-preference, time-preference, and intertemporal-substitution-preference elicitation tasks. Each of those tasks featured twenty decisions each. The fourth task was the uncertainty-resolution-preference elicitation task. It featured only one question. The first three tasks were adaptive: the first ten decisions would narrow a subject's preferences to a specific interval of parameter values, the next ten decisions would only focus on that specific interval, narrowing the elicited value of a subject's preferences further.[11]

3.1 Risk-preference elicitation task

In the risk-preference elicitation task, subjects made ten decisions identical to the framework of Holt and Laury (2002).[12] They chose between a safe option, a lottery between $8.00 and $6.00, and a risky option, a

[9]This payment was made a week after the last session to assure it did not interfere with payments made for the intertemporal-substitution-elicitation task.

[10]See our supplemental materials for the experimental instructions.

[11]Others refer to similar adaptive designs as the "chained method" (Wakker and Deneffe, 1996) or "iterated multiple price list" (see, for example, Andersen et al., 2006). In retrospect, it would have been better to randomize the ordering of the tasks across subjects. Harrison et al. (2005) demonstrate ordering effects from repeatedly using our risk-elicitation task under different stakes; there is no examination of ordering effects using different types of tasks. To execute our design, the second part of the risk-preference, time-preference and intertemporal-substitution-preference elicitation tasks had to occur after the first part, and the first part of the intertemporal-substitution-preference elicitation task had to occur after the second part of the time-preference elicitation task. Nonetheless, the tasks could have been randomly presented several ways and still preserved the previous essential orderings. We cannot, however, think of any specific effects that our ordering would generate in our data.

[12]This design was chosen over other risk-elicitation designs (e.g., Binswanger, 1980; Eckel and Grossman, 2008) because of its ability to estimate risk-preference parameters over fine regions (c.f., Dave et al., 2010).

lottery between \$15.40 and \$0.40 (see Figures 1a and 1b).[13] In decision 1, subjects chose between a gamble of \$8.00 (10% chance) and \$6.40 (90% chance) (in formal notation, (\$8.00, \$6.40; 0.1, 0.9)) and a gamble of \$15.40 (10% chance) and \$0.40 (90% chance) (in formal notation, (\$15.40, \$0.40; 0.1, 0.9)). In decision 10, they chose between \$8.00 and \$15.40 (that is (\$8.00, \$6.40; 1, 0) vs. (\$15.40, \$0.40; 1, 0)). The probability of the higher payoff option occurring increased linearly in between these decisions. That is, in decision n, subjects chose between lotteries (\$8.00, \$6.40; n/10, 1-n/10) and (\$15.40, \$0.40; n/10, 1-n/10).

The choice where subjects switched between options is called a switch point. Formally, a subject with a switch point n^*, has preferences as follows:

Definition 1 (Switch point for risk-preference elicitation)**.** *On the risk-preference elicitation task, a subject with a* switch point n^**, has preferences as follows:*

1. *The subject prefers the safe lottery for decisions,* $n < n^*$

$$\left(\$8.00, \$6.40; \frac{n}{10}, \frac{10-n}{10}\right) \succ \left(\$15.40, \$0.40; \frac{n}{10}, \frac{10-n}{10}\right) \quad \forall n < n^*$$

2. *The subject prefers the risky lottery for decisions,* $n \geq n^*$

$$\left(\$15.40, \$0.40; \frac{n}{10}, \frac{10-n}{10}\right) \succ \left(\$8.00, \$6.40; \frac{n}{10}, \frac{10-n}{10}\right) \quad \forall n \geq n^*$$

The last ten decisions in the risk-preference elicitation task examined a finer interval of lottery decisions to estimate a subject's risk parameter with more precision. The decisions featured the same lotteries and payoffs as before, but the probabilities in the lotteries were determined by a subject's switch point. The lotteries focused on the interval between a subject's last chosen safe lottery and first chosen risky lottery (the switch point). Thus, the subject's first ten decisions determined the next ten decisions he would be asked. So if a subject had a switch point on decision n^*, then in choice m, $1 \leq m \leq 10$, he would choose between the following lotteries[14]

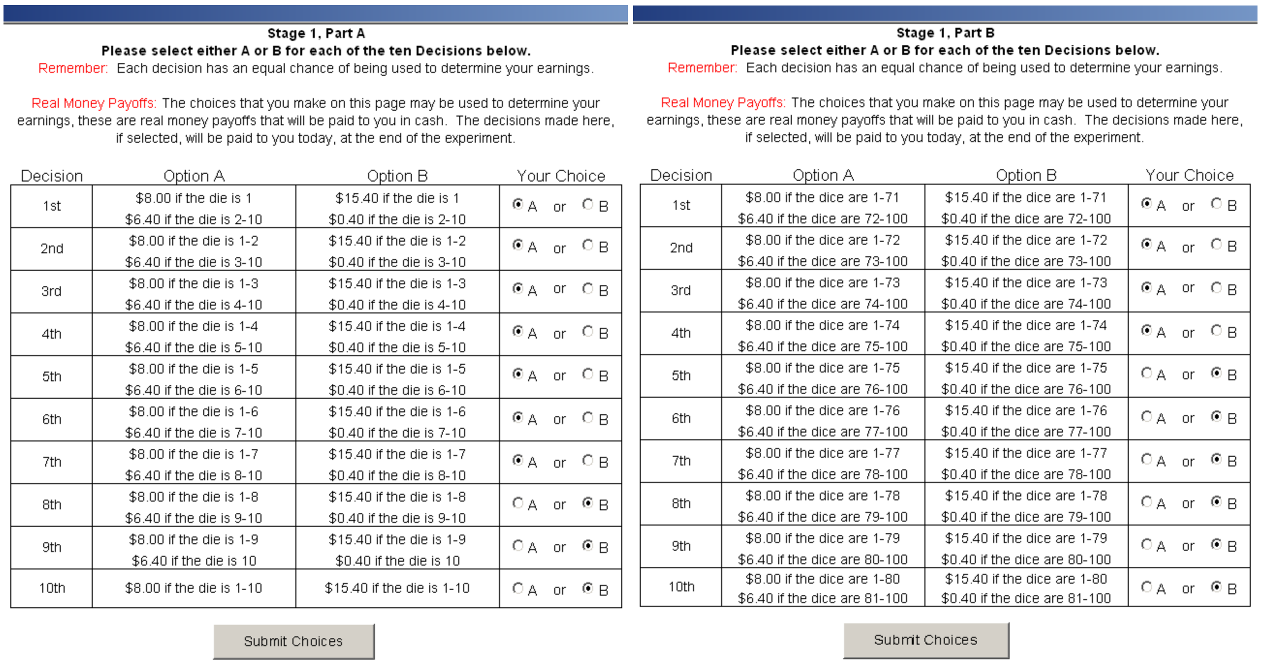
$$\left(\$8.00, \$6.40; \frac{10n^* + m - 10}{100}, \frac{110 - 10n^* - m}{100}\right),$$

$$\left(\$15.40, \$0.40; \frac{10n^* + m - 10}{100}, \frac{110 - 10n^* - m}{100}\right).$$

Figures 1a and 1b show screenshots of these twenty decisions. Note that this subject has a switch point at decision 8. Adapting to this choice, the last ten decisions concern lotteries where the probability of the high

[13]In their base setup, Holt and Laury (2002) used values of \$2.00 and \$1.60 for option A and \$3.85 and \$0.10 for option B, one fourth of the values described in our risk-preference elicitation task. In additional treatments they used 20, 50 and 90 times their original values (5, 12.5 and 22.5 times the values used here). In all cases the probability choices they used were identical to what was used in the first ten decisions of our risk-preference elicitation task.

[14]Note that these decisions are still a choice between a risky and safe lottery. The probability of the high payoff increases by 1% over each decision. The tenth question is identical to a previous question where a subject had first indicated they would choose the risky lottery (the switch point for risk-preference elicitation).



Stage 1, Part A
Please select either A or B for each of the ten Decisions below.
Remember: Each decision has an equal chance of being used to determine your earnings.

Real Money Payoffs: The choices that you make on this page may be used to determine your earnings, these are real money payoffs that will be paid to you in cash. The decisions made here, if selected, will be paid to you today, at the end of the experiment.

Decision	Option A	Option B	Your Choice
1st	$8.00 if the die is 1 $6.40 if the die is 2-10	$15.40 if the die is 1 $0.40 if the die is 2-10	◉ A or ○ B
2nd	$8.00 if the die is 1-2 $6.40 if the die is 3-10	$15.40 if the die is 1-2 $0.40 if the die is 3-10	◉ A or ○ B
3rd	$8.00 if the die is 1-3 $6.40 if the die is 4-10	$15.40 if the die is 1-3 $0.40 if the die is 4-10	◉ A or ○ B
4th	$8.00 if the die is 1-4 $6.40 if the die is 5-10	$15.40 if the die is 1-4 $0.40 if the die is 5-10	◉ A or ○ B
5th	$8.00 if the die is 1-5 $6.40 if the die is 6-10	$15.40 if the die is 1-5 $0.40 if the die is 6-10	◉ A or ○ B
6th	$8.00 if the die is 1-6 $6.40 if the die is 7-10	$15.40 if the die is 1-6 $0.40 if the die is 7-10	◉ A or ○ B
7th	$8.00 if the die is 1-7 $6.40 if the die is 8-10	$15.40 if the die is 1-7 $0.40 if the die is 8-10	◉ A or ○ B
8th	$8.00 if the die is 1-8 $6.40 if the die is 9-10	$15.40 if the die is 1-8 $0.40 if the die is 9-10	○ A or ◉ B
9th	$8.00 if the die is 1-9 $6.40 if the die is 10	$15.40 if the die is 1-9 $0.40 if the die is 10	○ A or ◉ B
10th	$8.00 if the die is 1-10	$15.40 if the die is 1-10	○ A or ◉ B

Submit Choices

Stage 1, Part B
Please select either A or B for each of the ten Decisions below.
Remember: Each decision has an equal chance of being used to determine your earnings.

Real Money Payoffs: The choices that you make on this page may be used to determine your earnings, these are real money payoffs that will be paid to you in cash. The decisions made here, if selected, will be paid to you today, at the end of the experiment.

Decision	Option A	Option B	Your Choice
1st	$8.00 if the dice are 1-71 $6.40 if the dice are 72-100	$15.40 if the dice are 1-71 $0.40 if the dice are 72-100	◉ A or ○ B
2nd	$8.00 if the dice are 1-72 $6.40 if the dice are 73-100	$15.40 if the dice are 1-72 $0.40 if the dice are 73-100	◉ A or ○ B
3rd	$8.00 if the dice are 1-73 $6.40 if the dice are 74-100	$15.40 if the dice are 1-73 $0.40 if the dice are 74-100	◉ A or ○ B
4th	$8.00 if the dice are 1-74 $6.40 if the dice are 75-100	$15.40 if the dice are 1-74 $0.40 if the dice are 75-100	◉ A or ○ B
5th	$8.00 if the dice are 1-75 $6.40 if the dice are 76-100	$15.40 if the dice are 1-75 $0.40 if the dice are 76-100	○ A or ◉ B
6th	$8.00 if the dice are 1-76 $6.40 if the dice are 77-100	$15.40 if the dice are 1-76 $0.40 if the dice are 77-100	○ A or ◉ B
7th	$8.00 if the dice are 1-77 $6.40 if the dice are 78-100	$15.40 if the dice are 1-77 $0.40 if the dice are 78-100	○ A or ◉ B
8th	$8.00 if the dice are 1-78 $6.40 if the dice are 79-100	$15.40 if the dice are 1-78 $0.40 if the dice are 79-100	○ A or ◉ B
9th	$8.00 if the dice are 1-79 $6.40 if the dice are 80-100	$15.40 if the dice are 1-79 $0.40 if the dice are 80-100	○ A or ◉ B
10th	$8.00 if the dice are 1-80 $6.40 if the dice are 81-100	$15.40 if the dice are 1-80 $0.40 if the dice are 81-100	○ A or ◉ B

Submit Choices

Figure 1: The risk-preference elicitation task. (a, left) A subject makes 10 decisions between safe and risky lotteries. This subject makes 7 safe choices and 3 risky. (b, right) The subject makes the next 10 decisions between safe and risky lotteries on the interval between his last safe choice (($8.00, $6.40; 0.7, 0.3) over ($15.40, $0.40; 0.7, 0.3)) and his first risky choice (($15.40, $0.40; 0.8, 0.2) over ($8.00, $6.40; 0.8, 0.2)) from his first ten decisions.

payoff is on the interval (0.7, 0.8].

3.2 Time-preference elicitation task

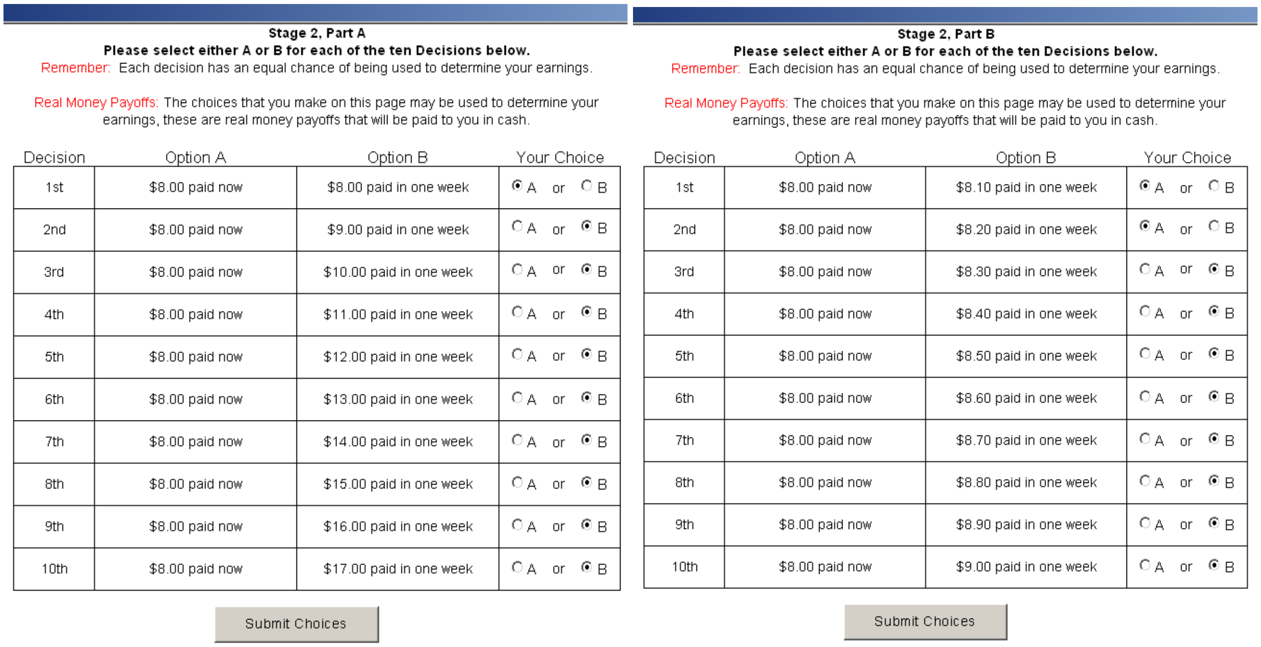
Similar to Coller and Williams (1999), the second task elicited subjects' time preferences, specifically their preference for $8.00 now versus an amount of money they would receive in the follow-up experimental session one week later. In their first ten decisions, subjects were asked to choose between $8.00 immediately and an increasing amount of money in one week ($8.00, $9.00, $10.00, $11.00, $12.00, $13.00, $14.00, $15.00, $16.00, and $17.00).

Similar to the previously-mentioned, risk-preference elicitation task, the time-preference elicitation task adaptively asked decisions at the point where subjects switched responses. Formally, a subject has a switch point x^* defined as follows:

Definition 2 (Switch point for time-preference elicitation)**.** *On the time-preference elicitation task, a subject with a* switch point x^**, has preferences as follows:*

1. *The subject prefers the immediate choice,* \$8.00 *now, to* $\$(8 + x - 1)$ *in one week, for all* $x < x^*$.
2. *The subject prefers the later choice choice,* $\$(8 + x - 1)$ *in one week, to* \$8.00 *now, for all* $x \geq x^*$.

If a subject has a switch point of x^*, so that he prefers \$8.00 now to $\$8+x^*-2$ in one week, but $\$8+x^*-1$ in one week to \$8.00 now, the next ten decisions would ask the subject to decide between \$8.00 now and



Stage 2, Part A
Please select either A or B for each of the ten Decisions below.
Remember: Each decision has an equal chance of being used to determine your earnings.

Real Money Payoffs: The choices that you make on this page may be used to determine your earnings, these are real money payoffs that will be paid to you in cash.

Decision	Option A	Option B	Your Choice
1st	$8.00 paid now	$8.00 paid in one week	◉ A or ○ B
2nd	$8.00 paid now	$9.00 paid in one week	○ A or ◉ B
3rd	$8.00 paid now	$10.00 paid in one week	○ A or ◉ B
4th	$8.00 paid now	$11.00 paid in one week	○ A or ◉ B
5th	$8.00 paid now	$12.00 paid in one week	○ A or ◉ B
6th	$8.00 paid now	$13.00 paid in one week	○ A or ◉ B
7th	$8.00 paid now	$14.00 paid in one week	○ A or ◉ B
8th	$8.00 paid now	$15.00 paid in one week	○ A or ◉ B
9th	$8.00 paid now	$16.00 paid in one week	○ A or ◉ B
10th	$8.00 paid now	$17.00 paid in one week	○ A or ◉ B

Submit Choices

Stage 2, Part B
Please select either A or B for each of the ten Decisions below.
Remember: Each decision has an equal chance of being used to determine your earnings.

Real Money Payoffs: The choices that you make on this page may be used to determine your earnings, these are real money payoffs that will be paid to you in cash.

Decision	Option A	Option B	Your Choice
1st	$8.00 paid now	$8.10 paid in one week	◉ A or ○ B
2nd	$8.00 paid now	$8.20 paid in one week	◉ A or ○ B
3rd	$8.00 paid now	$8.30 paid in one week	○ A or ◉ B
4th	$8.00 paid now	$8.40 paid in one week	○ A or ◉ B
5th	$8.00 paid now	$8.50 paid in one week	○ A or ◉ B
6th	$8.00 paid now	$8.60 paid in one week	○ A or ◉ B
7th	$8.00 paid now	$8.70 paid in one week	○ A or ◉ B
8th	$8.00 paid now	$8.80 paid in one week	○ A or ◉ B
9th	$8.00 paid now	$8.90 paid in one week	○ A or ◉ B
10th	$8.00 paid now	$9.00 paid in one week	○ A or ◉ B

Submit Choices

Figure 2: The time-preference elicitation task. (a, left) In the time-preference elicitation task, a subject makes 10 decisions between $8 paid immediately and money in one week. This subject chooses $8 now over $8 in one week, but selects $9 in one week over $8 now. (b, right) In the next ten decisions, subjects choose between $8 paid immediately and money in one week between the highest amount of money they refused in one week ($8.00 in this example) and the lowest amount of money they accepted in one week ($9.00 in this example).

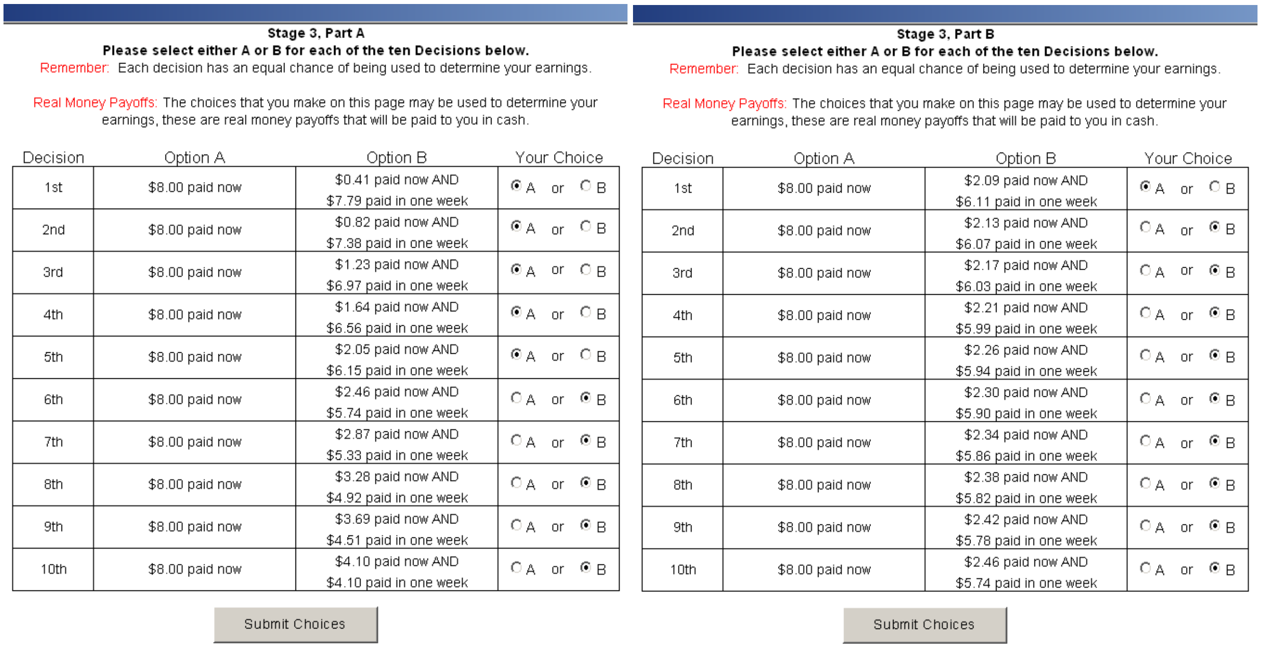
money in one week on the interval [$6.10+$x^*$, $7+$x^*$]. That is, subjects would make ten choices between $8.00 now and $$x^*$+6.10, $$x^*$+6.20, $$x^*$+6.30, $$x^*$+6.40, $$x^*$+6.50, $$x^*$+6.60, $$x^*$+6.70, $$x^*$+6.80, $$x^*$+6.90, and $$x^* + 7.00$ in one week (see Figure 2b).

3.3 Intertemporal-substitution-preference elicitation task

The third task elicited subjects' intertemporal-substitution preferences, preferences which showed how they felt about smoothing cash payments from one week to another. The last switch point from the final ten decisions of the time-preference elicitation task was used as a baseline. This value is the highest amount of money a subject would refuse in one week over $8 today (in Figure 2b, it is $8.20). Subjects were asked to make ten decisions between $8 now and a percentage (i.e., 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%) of the baseline now and the remainder paid in one week. The total amount of money given in the second option was always the amount of the baseline (in Figure 3a, the total is always $8.20).

Like the previously-mentioned, risk-preference and time-preference elicitation tasks, the intertemporal-substitution-preference elicitation task featured an adaptive design. The last ten decisions of the intertemporal-substitution-preference elicitation task were determined by a subject's switch point in the first ten decisions. Formally, a subject has a switch point z^* where

Definition 3 (Switch-point for intertemporal-substitution-preference elicitation)**.** *On the intertemporal-substitution-*



Stage 3, Part A

Please select either A or B for each of the ten Decisions below.

Remember: Each decision has an equal chance of being used to determine your earnings.

Real Money Payoffs: The choices that you make on this page may be used to determine your earnings, these are real money payoffs that will be paid to you in cash.

Decision	Option A	Option B	Your Choice
1st	$8.00 paid now	$0.41 paid now AND $7.79 paid in one week	◉A or ○B
2nd	$8.00 paid now	$0.82 paid now AND $7.38 paid in one week	◉A or ○B
3rd	$8.00 paid now	$1.23 paid now AND $6.97 paid in one week	◉A or ○B
4th	$8.00 paid now	$1.64 paid now AND $6.56 paid in one week	◉A or ○B
5th	$8.00 paid now	$2.05 paid now AND $6.15 paid in one week	◉A or ○B
6th	$8.00 paid now	$2.46 paid now AND $5.74 paid in one week	○A or ◉B
7th	$8.00 paid now	$2.87 paid now AND $5.33 paid in one week	○A or ◉B
8th	$8.00 paid now	$3.28 paid now AND $4.92 paid in one week	○A or ◉B
9th	$8.00 paid now	$3.69 paid now AND $4.51 paid in one week	○A or ◉B
10th	$8.00 paid now	$4.10 paid now AND $4.10 paid in one week	○A or ◉B

Submit Choices

Stage 3, Part B

Please select either A or B for each of the ten Decisions below.

Remember: Each decision has an equal chance of being used to determine your earnings.

Real Money Payoffs: The choices that you make on this page may be used to determine your earnings, these are real money payoffs that will be paid to you in cash.

Decision	Option A	Option B	Your Choice
1st	$8.00 paid now	$2.09 paid now AND $6.11 paid in one week	◉A or ○B
2nd	$8.00 paid now	$2.13 paid now AND $6.07 paid in one week	○A or ◉B
3rd	$8.00 paid now	$2.17 paid now AND $6.03 paid in one week	○A or ◉B
4th	$8.00 paid now	$2.21 paid now AND $5.99 paid in one week	○A or ◉B
5th	$8.00 paid now	$2.26 paid now AND $5.94 paid in one week	○A or ◉B
6th	$8.00 paid now	$2.30 paid now AND $5.90 paid in one week	○A or ◉B
7th	$8.00 paid now	$2.34 paid now AND $5.86 paid in one week	○A or ◉B
8th	$8.00 paid now	$2.38 paid now AND $5.82 paid in one week	○A or ◉B
9th	$8.00 paid now	$2.42 paid now AND $5.78 paid in one week	○A or ◉B
10th	$8.00 paid now	$2.46 paid now AND $5.74 paid in one week	○A or ◉B

Submit Choices

Figure 3: The intertemporal-substitution-preference elicitation task. (a, left) In the intertemporal-substitution-preference elicitation task a subject's first ten decisions are between $8 immediately and a baseline ($8.20), split between now and in one week. The $8.20 baseline amount is the highest amount of money paid in one week that a subject prefers less than $8 paid immediately (see Figure 2b, 2nd decision). (b, right): In the last ten decisions subjects choose between $8 paid immediately and a baseline ($8.20), split between now and in one week. In all decisions the percentage of the baseline paid now is between 25% and 30%. The value 25% is the highest amount of the baseline paid immediately that the subject prefers less than $8 immediately (Figure 3a, 5th decision) and 30% is the lowest amount of the baseline paid now that in the split that the subject prefers to $8 immediately (Figure 3a, 6th decision).

preference elicitation task, a subject with a switch point z^*, *has preferences as follows:*

1. *The subject prefers the single payment,* $\$8.00$ *now to the joint payment of* $(5z)\%$ *of the baseline now and* $(100-5z)\%$ *of the baseline in one week, for all* $z < z^*$.

2. *The subject prefers the later choice choice, the joint payment of* $(5z)\%$ *of the baseline now and* $(100-5z)\%$ *of the baseline in one week, to* $\$8.00$ *now, for all* $z \geq z^*$.

If a subject's first ten decisions determine that he has a switch point of z^*, then his last ten decisions will be between $8.00 now and a percentage of his baseline on the interval $[(5(z^*-1)+0.5)\%, (5z^*)\%]$ now and the remaining percentage later. That is, the subject will choose between $8.00 now and 5($z^*$-1)+0.5)%, (5($z^*$-1)+1)%, (5($z^*$-1)+1.5)%, (5($z^*$-1)+2)%, (5($z^*$-1)+2.5)%, (5($z^*$-1)+3)%, (5($z^*$-1)+3.5)%, (5($z^*$-1)+4.5)%, and (5$z^*$)% of the baseline now and the remainder in one week.

Figure 3a provides an example. The subject's baseline is $8.20. The first ten decisions reveal the subject prefers $8.00 now to 25% of his baseline now and 75% in one week, but prefers 30% of his baseline now and 70% in one week to $8.00 immediately. The subject would have a switch point of 6. The last ten decisions feature choices between $8.00 paid immediately and a percentage of his baseline, between 25% and 30%, paid immediately and the remainder is paid later.

Given its greater complexity than the risk and time preference elicitation tasks and its first use in this paper, an additional description should be given for the intertemporal-substitution-preference elicitation task. Notice that if we look over the choices for option B (see Figures 3a and 3b), they become progressively more attractive in terms of time-discounting (as more cash is given immediately) and intertemporal smoothing (as cash is more evenly distributed between two periods). If a subject makes consistent choices (choosing option A exclusively before choosing option B) on the task and switches early, preferring option B on more choices than option A, then he exhibits a preference for intertemporal smoothing, hence lower elasticity of substitution. If instead, a subject waits until the last few decisions to choose option B, or does not choose option B at all, he is exhibiting very low if any preference for intertemporal smoothing, or high elasticity of substitution.

In other words, a subject with a strong preference for income smoothing will accept almost any payment given in multiple periods than having \$8.00 now. The utility lost by having money later is offset by the gain for having that money smoothed. He will choose Option B in nearly all cases. A subject with a weaker preference for smoothing won't prefer option B until the later choices as the utility loss from having money later is greater than the gain from having payments smoothed. Granted these choices are also dependent on subjects' parameters for time-preference, and both parameters will need to be estimated jointly (see the results section for more on this issue). But the general result that subjects with a greater preference for smoothing will switch earlier than subjects with a lower preference will hold absolutely over subjects with identical time-preference parameters.

3.4 Uncertainty-resolution-preference elicitation task

The uncertainty-resolution preference elicitation task featured only one choice between three options. Subjects were told they would receive \$20 in two weeks with 0.5 probability based on the result of a die roll. They could choose to roll the die immediately, in one week, or let the computer randomly select (either choice with equal probability). If subjects chose to let the computer decide they would receive an additional one-cent, for a payment of \$20.01 on the lottery's positive outcome. This extra cent bonus was added to ensure that subjects truly indifferent between the three choices (as standard expected utility models predict) would have a clear option to choose and would not randomize over the three choices.

3.5 Subject payment and follow-up session

After subjects finished making their choices, they were called to roll one four sided die and two ten sided dice to determine how they would be paid. The four sided die determined from which task they would receive their payments. Subjects that rolled a 1, 2, 3, or 4 would be paid for the risk-preference, time-preference, intertemporal-substitution-preference, or uncertainty-resolution preference elicitation tasks, respectively. If the first three tasks were chosen, the ten sided die was used to determine if the payment would come from decisions made in the first or last set of ten decisions. If subjects rolled a 0, the last ten decisions would be

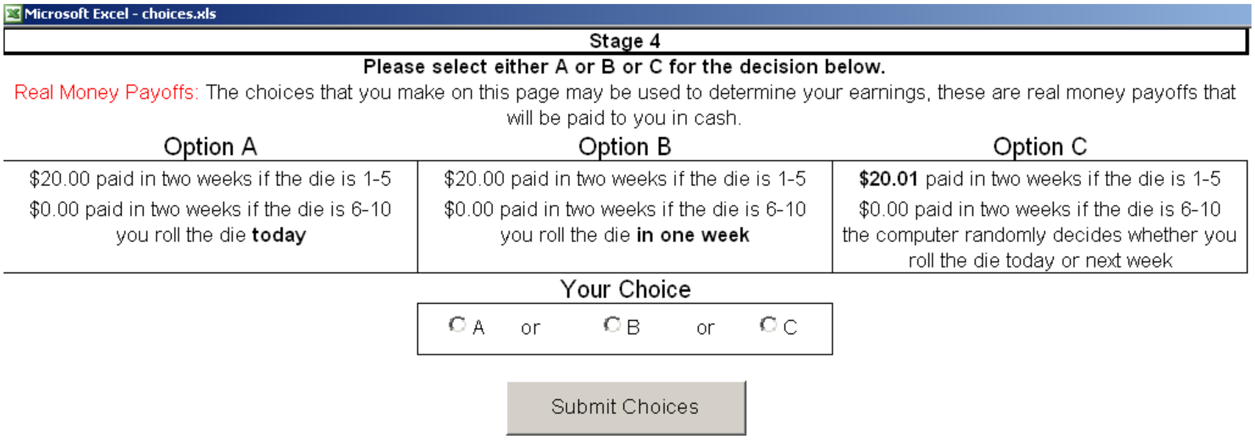


Figure 4: The uncertainty-resolution-preference elicitation task. Subjects are told about a lottery for $20 determined by a die roll. They can choose to roll the die today, in one week, or let the computer choose for them. If the computer chooses they will get an additional $0.01 if they win the lottery (to entice indifferent subjects to choose Option C).

used. If subjects rolled a 1–9, the first ten decisions would be used.[15] The other ten sided die determined which of the ten decisions would be used for payment. Subjects were paid exactly how each decision had stated. If the decision specified another die (or dice) roll (i.e., the risk-preference elicitation task), subjects would roll again to determine their payment.

Subjects came back one week later for a follow-up session.[16] In that session subjects received payment for any decisions that required it (possibly time-preference or intertemporal-substitution-preference elicitation tasks). All subjects completed surveys on psychological risk, impulsivity, and their personal value of uncertainty resolution.[17] Subjects that had been selected to be paid on the uncertainty-resolution elicitation task and were to roll in one week, rolled at this time. Finally, all subjects self-addressed envelopes and filled out $20 money orders for their participation payment that would be sent to them in one week. Subjects that were to be paid based on the uncertainty-resolution elicitation task and had rolled successfully also received an additional money order to mail for $20.00 or $20.01 depending on their choices for that task.

[15]To avoid subjects exploiting the adaptive elicitation method in this experiment, the first set of 10 decisions were 9 times more likely to be selected than the second set. This would prevent a subject from, for example, falsely claiming $17 is the minimum preferred in one week to $8 (rather than honestly admitting $9 in one week is preferred to $8 now) to set up a second set of questions that feature choices between $16–$17 in the second stage of the time-preference elicitation task (rather than choices between $8–$9). The experimental instructions informed subjects of exactly how the dice rolls would work. In order not to confuse subjects, the instructions stated in the final paragraph, "While this randomization procedure may seem complicated, your strategy need not be. Rather than worry about the "right" answer—there isn't one—consider how you would like to be paid and select your options accordingly."

[16]Ninety-four of 101 (93%) subjects returned for their follow-up session. Mann-Whitney tests reveal no significant differences by the implied preferences (determined from second switch point, see Section 5.2 for values) on the risk-preference, time-preference, or intertemporal-substitution-preference elicitation tasks, or the choice of early resolution on the uncertainty-resolution-preference elicitation task at the 10% level between subjects that returned for the second session and those who did not.

[17]See our supplemental materials for full surveys. The survey responses had little correlation with subject choices. They are not reported in this paper. We do include them and a brief description of their relevance in our regressions on subject switch points found in our supplemental materials.

Experimenters sealed money orders in envelopes and mailed them 3–5 days before their intended delivery day. The intended delivery day was two weeks after the first experimental session and one week after the follow-up experimental session.

4 Theoretical predictions

Subject responses from the risk-preference elicitation task provide an estimate of each subject's risk-preference parameter (α). Subject responses from the time-preference and intertemporal-substitution-preference elicitation tasks provide an estimate of each subject's time-preference (β) and intertemporal-substitution-preference (ρ) parameters.

Recall from Theorem 2 that each subject that has risk-preference parameters less than intertemporal-substitution-preference parameters ($\alpha < \rho$) should prefer early resolution of uncertainty; they should choose to roll immediately in the uncertainty-resolution-preference elicitation task. Each subject that has risk-preference parameters greater than intertemporal-substitution-preference parameters ($\alpha > \rho$) should prefer late resolution of uncertainty; they should choose to roll in one week in the uncertainty-resolution-preference elicitation task. Subjects that have risk-preference and intertemporal-substitution-preference parameters that are not significantly different ($\alpha \approx \rho$), should be indifferent between early and late resolution of uncertainty; they should choose to let the computer randomly decide when they roll, receiving a marginal bonus, in the uncertainty-resolution-preference elicitation task. Expected utility theory predicts that subjects should always be indifferent between early and late resolution of uncertainty. Under that theory, all subjects should choose to let the computer decide when they roll. Additionally, power utility models of expected utility suggest a direct relationship between the elasticity of intertemporal substitution and risk preference. In this formalization, all subjects should behave so that $\alpha \approx \rho$.

5 Results

5.1 Summary results of preference elicitation

One hundred and one subjects participated in the four elicitation tasks. Table 1 and Figure 5 show the decisions subjects made in the risk-preference elicitation task. All subjects chose the riskier lottery in at least one of their decisions. The "number of subjects" column in the table and the "frequency" measure in the histogram shows how many subjects switched to the risky option for the first time when confronted with that choice. In other words, it tells how many subjects had that value as their switch point (e.g., 6 subjects had a switch point of 4). Most subjects did not switch until at least the sixth choice (74/101, 73%), displaying a degree of risk-aversion. Nineteen subjects (19%) switched at the fifth choice where a risk-neutral subject would switch. Only 8 subjects (8%) switched earlier than the fifth choice, indicating a degree of risk-seeking behavior.[18] The results are quite similar to Holt and Laury (2002) who find median switch points of 6 or

[18] Of the 101 subjects only 7 made inconsistent choices (choosing Option A after choosing Option B) in the risk-preference elicitation task. Five of the 7 made their inconsistent choices in their first ten decisions. Of these 5, 1 chose option B immediately, 2 chose option B at the fourth decision. All would be classified as risk-seeking in Table 1. The other 2 chose option B first at the

Lottery A	Lottery B	CRRA Interval if Subject Switches to Lottery B and wealth is 0	number of subjects[a]	percent of subjects
(0.1,0.9;8.00,6.40)	(0.1,0.9;15.40,0.40)	$(2.71, \infty)$	2	0.02
(0.2,0.8;8.00,6.40)	(0.2,0.8;15.40,0.40)	(1.95, 2.71)	0	0.00
(0.3,0.7;8.00,6.40)	(0.3,0.7;15.40,0.40)	(1.49, 1.95)	0	0.00
(0.4,0.6;8.00,6.40)	(0.4,0.6;15.40,0.40)	(1.14, 1.49)	6	0.06
(0.5,0.5;8.00,6.40)	(0.5,0.5;15.40,0.40)	(0.85, 1.14)	19	0.19
(0.6,0.4;8.00,6.40)	(0.6,0.4;15.40,0.40)	(0.59, 0.85)	23	0.23
(0.7,0.3;8.00,6.40)	(0.7,0.3;15.40,0.40)	(0.32, 0.59)	30	0.30
(0.8,0.2;8.00,6.40)	(0.8,0.2;15.40,0.40)	(0.03, 0.32)	16	0.16
(0.9,0.1;8.00,6.40)	(0.9,0.1;15.40,0.40)	(-0.37, 0.03)	5	0.05
(1,0;8.00,6.40)	(1,0;15.40,0.40)	$(-\infty, -0.37)$	0	0.00

Table 1: Aggregate results of risk-preference elicitation task, first 10 decisions. Lottery A has higher expected value than lottery B for the first 4 choices, then B has higher expected value.
a. Number of subjects includes all subjects that *first* chose option B at that decision.

7, with low and high stakes choices, respectively. The second set of 10 risky decisions allows us to further calibrate subject preferences. Figure 5b shows a histogram of subjects' switch point on these tasks. Section 5.2 calculates individual subject risk preferences implied by this second switch point.

In the time-preference elicitation task, subjects gave their preference between \$8 now and a dollar amount in one week. Table 2 and Figure 6a show the results of these choices. More than half of the subjects (56), preferred \$8.00 to \$8.00 in one week, but chose \$9 in one week to \$8 now. This would be considered a switch point of 2 in Figure 6a. Nearly all the other subjects (42) needed more money in one week (greater than \$9) to prefer money in one week to \$8 now. These results are not consistent with annualized interest rates in financial markets, but are not that different from elicited answers in similar type elicitation tasks with both student and non-student populations (see Frederick et al., 2002, for a survey).[19] Additionally, these results do not consider the curvature of subject utility functions, which will be calibrated in the intertemporal-substitution-preference elicitation task. As explained in Frederick et al., section 6.1.3, neglecting to account for the curvature of utility overestimates the rate at which subjects discount the future. The next two sections (Sections 5.2 and 5.3) will estimate β parameters making use of the results from both tasks.

Subjects' time preferences were further elicited in the last ten decisions of the time-preference elicitation task (see Figure 6b). In that stage subjects chose between \$8 now and dollar amounts based on their switch point in the first ten decisions. Those values were given in 10 cent increments. From these choices the highest amount of money a subject would refuse in one week to \$8 immediately was calculated. This value is referred to as the "baseline" in the intertemporal-substitution-preference elicitation task. The mean subject baseline amount was \$9.46 (median \$8.90) with standard deviation \$1.90. This baseline amount, the

fifth decision, an action classified as risk-neutral in Table 1.

[19] Four of the 101 subjects chose Option A after choosing Option B. One of these decisions occurred in the first 10 decisions for a subject who was classified as preferring \$8 in one week to \$8 now. Thus, all but one subject were consistent for their choices given in Table 2.

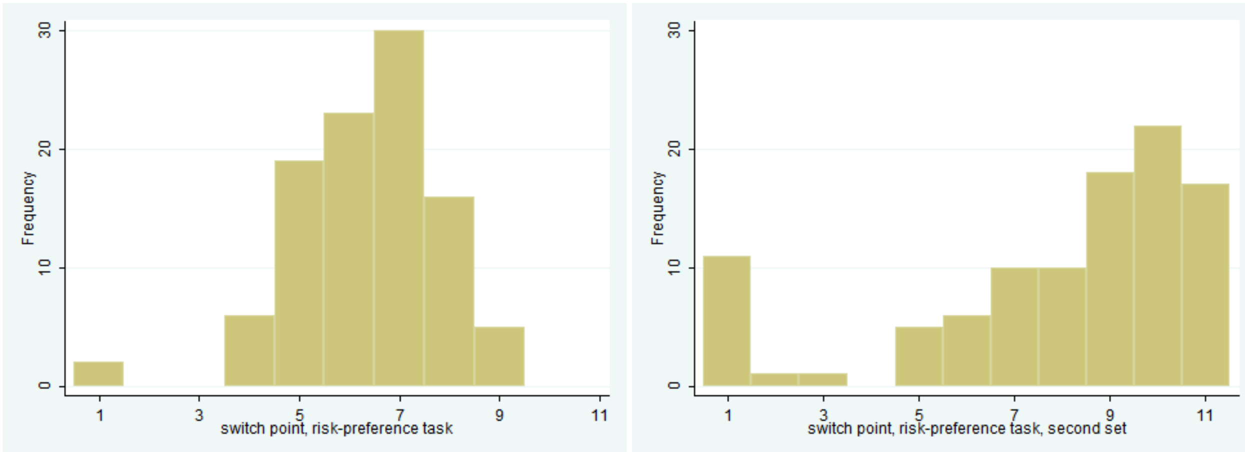


Figure 5: Histogram of subject switch points in the risk-preference elicitation task. (a, left): Subjects' switch point in first 10 decisions. switch points below 5, at 5 and above 5 imply risk-seeking, risk-neutral, and risk-averse behaviors respectively (most subjects have switch points that imply risk-aversion). See Table 1 for parameter estimates implied by each switch point. (b, right): Subjects' switch point in second 10 decisions. All ten decisions fall on the interval between the last chosen safe decision and the first chosen risky decision. See Figure 1 for a diagram of the risk-preference elicitation task.

Payment Option A (pays amount now)	Payment Option B (pays amount in 1 week)	Annual Simple Interest Rate	number of subjects[a]	percent of subjects
$8.00	$8.00	0%	3	0.03
8.00	9.00	650%	56	0.55
8.00	10.00	1300%	17	0.17
8.00	11.00	1950%	8	0.08
8.00	12.00	2600%	4	0.04
8.00	13.00	3250%	6	0.06
8.00	14.00	3900%	1	0.01
8.00	15.00	4550%	5	0.05
8.00	16.00	5200%	1	0.01
8.00	17.00	5850%	0	0.00

Table 2: Aggregate results of time-preference elicitation task, first 10 decisions.
a. Number of subjects includes all subjects that *first* chose option B at that decision.

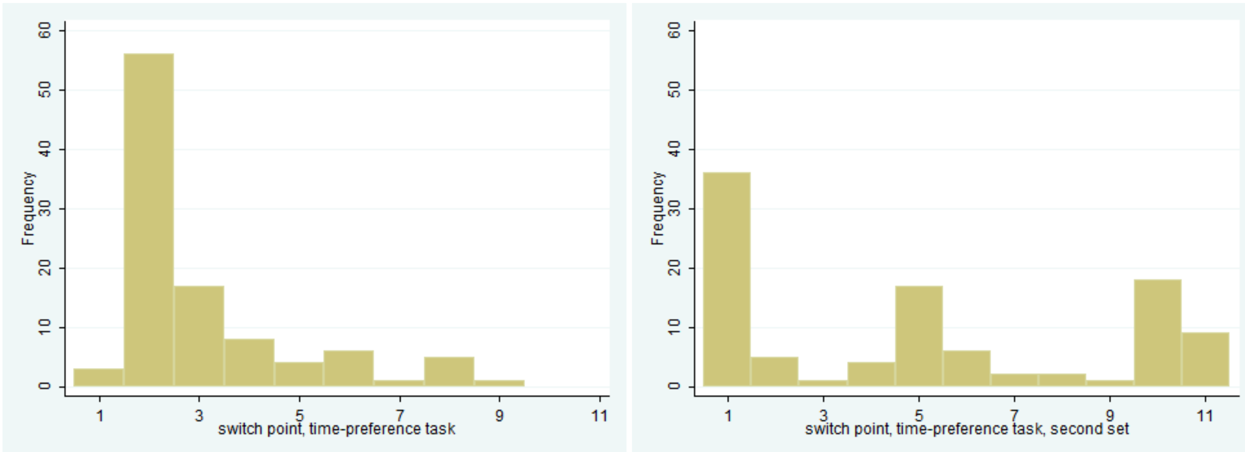


Figure 6: Histogram of subject switch points in the time-preference elicitation task. (a, left): Subjects' switch point in first 10 decisions. See Table 2 for annual simple interest rates implied by each switch point. (b, right): Subjects' switch point in second 10 decisions. Subjects choose between \$8 paid immediately and money in one week between the highest amount of money they refused in one week and the lowest amount of money they accepted in one week in the previous 10 decisions. See Figure 2 for a diagram of the time-preference elicitation task.

highest amount of money a subject would refuse in one week to \$8 immediately, was used to elicit subjects' intertemporal-substitution preferences.

In the intertemporal-substitution-preference elicitation task, subjects were asked to choose between \$8 now and a percentage of their baseline amount now and the remaining percentage in one week. These percentages started at 5% now and 95% in one week and eventually moved to 50% now and 50% in one week. Table 3 and Figure 7a show subject choices at the first part of this stage.[20] Table 3 also shows the possible ρ values for subjects if their baseline value was \$8.90. The specific value for the parameter of intertemporal-substitution-preference, ρ, is determined by subject decisions in both the time-preference and intertemporal-substitution-preference elicitation tasks. Subjects with different baseline values that have the same switch point on the intertemporal-substitution-preference elicitation task (e.g., they both switch for 30% of baseline now) can still have dramatically different values of ρ. For instance, Table 3 suggests only 24 subjects have implied intervals of ρ that contain parameter values less than 1, when based on their second switch point, 40 subjects actually do (see Section 5.2). This occurs because not all subjects have \$8.90 as their baseline.

The distribution of subject responses divides between two extremes. Twenty subjects (20%) will accept the baseline amount (the money they refused to take in one week instead of \$8.00 immediately) provided 5% is given immediately, indicating a preference for consumption smoothing. Another 48 subjects (48%) will not take the baseline amount of money even if it is split half between this week and next week. Since those who choose Option B earlier will have lower elasticity of intertemporal substitution, this result suggests that

[20]Seventeen of the 101 subjects chose Option A after choosing Option B. Sixteen deviated in in these first ten decisions (4 of these 16 also deviated in the last ten decisions). Of the 16, 7 chose Option B in their first choice, 3 in their second, 2 in their fifth, 4 in their sixth, and 1 in their ninth.

Option A	Option B (percent of baseline[a] now, percent of baseline in 1 week)	Open p interval if subject switches to Option B at this decision with baseline[a] of $8.90	number of subjects[b]	percent of subjects
$8.00	(0.05, 0.95)	(0.000, 1.028)	20	0.20
8.00	(0.10, 0.90)	(0.978, 1.034)	4	0.04
8.00	(0.15, 0.85)	(1.004, 1.040)	4	0.04
8.00	(0.20, 0.80)	(1.017, 1.045)	1	0.01
8.00	(0.25, 0.75)	(1.027, 1.050)	5	0.05
8.00	(0.30, 0.70)	(1.035, 1.056)	6	0.06
8.00	(0.35, 0.65)	(1.043, 1.062)	3	0.03
8.00	(0.40, 0.60)	(1.050, 1.069)	1	0.01
8.00	(0.45, 0.55)	(1.058, 1.077)	4	0.04
8.00	(0.50, 0.50)	(1.067, 1.086)	5	0.05
never chose option B		(1.077, ∞)	48	0.48

Table 3: Aggregate results of intertemporal-substitution-preference elicitation task, first 10 decisions.
a. Baseline is the highest amount of money in one week not preferred to $8.00 in the time-preference elicitation task. It varies for all subjects.
b. Number of subjects includes all subjects that *first* chose option B at that decision.

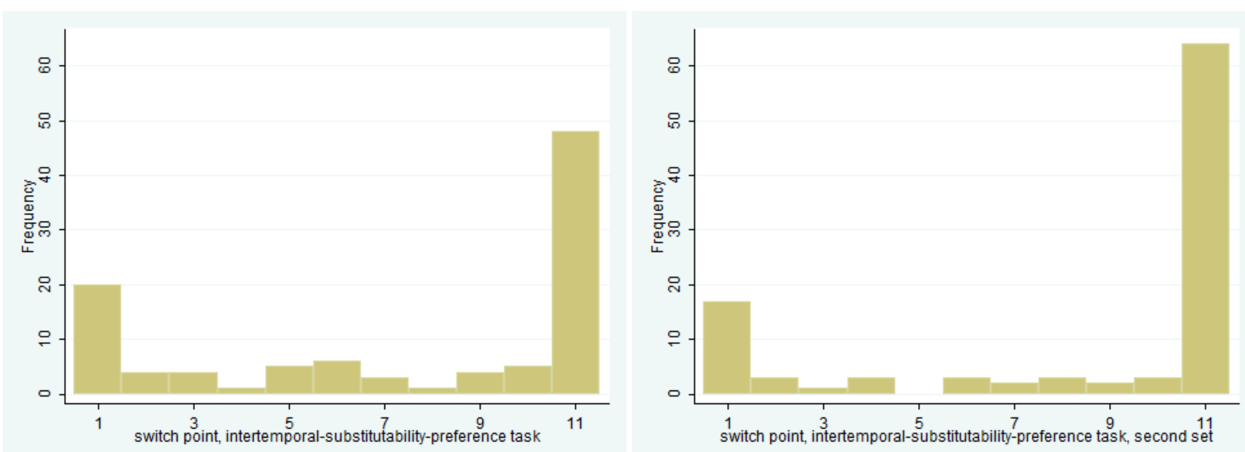


Figure 7: Histogram of subject switch points in the intertemporal-substitution-preference elicitation task. (a, left): Subjects' switch point in first 10 decisions. See Table 3 for ρ values implied by each switch point under a $8.90 baseline. (b, right): Subjects' switch point in second 10 decisions. See Figure 3 for a diagram of the intertemporal-substitution-preference elicitation task.

the majority of subjects have high intertemporal substitution. A similar relation is also found in the second 10 decisions (Figure 7b), though more subjects choose not to switch throughout the second 10 decisions (64 subjects, 63%, have a second switch point of 11). A total of 47 subjects (47%) do not switch to the smoother option on either the first or second 10 decisions on intertemporal-substitution-preference elicitation task (i.e., switch points of 11 on both the first and second 10 decisions). This result is reminiscent of Andreoni and Sprenger (2012), who use a different design over longer time periods (up to 100 days), and find 37 of their 97 subjects always choose no smoothing (36%), though the implications of that choice are different under their design.

In the uncertainty-resolution-preference elicitation task, subjects chose between three lotteries: one equally likely to pay \$20 or \$0 in two weeks with the uncertainty resolved now, one equally likely to pay \$20 or \$0 in two weeks with the result given in one week, or one lottery equally likely to pay \$20.01 or \$0 in two weeks where the result would be randomly decided now or in one week. A majority of subjects (61 of 101, 60%) preferred to have uncertainty resolved early and chose the first lottery. Three subjects preferred to have uncertainty resolved late and chose the second lottery. Thirty-eight subjects (37%) chose the third lottery indicating near indifference for the timing of resolution. Our results are not all that different from other studies that ask similar hypothetical questions (Chew and Ho, 1994; Ahlbrecht and Weber, 1997), using a variety of stakes (i.e., both losses and gains up to thousands of dollars), over different time periods (up to two months) and find roughly 40-60% of subjects prefer early resolution. Of the remainder more are indifferent than prefer late resolution.

Our results show that most subjects are risk averse, prefer more intertemporal substitution and early resolution of uncertainty.[21] This is broadly consistent with Theorem 2. While the remainder of the paper further analyzes this using the estimates of the parameterized Epstein-Zin preference function, it is important to highlight that the basic experiment results suggest that risk aversion, intertemporal substitution and uncertainty resolution are closely linked to each other, as stated by the theory.

5.2 Subject preference parameters implied by their second switch point and their correlations

For illustrative purposes, it is desirable to connect the switch points observed in the previous section with actual parameter values for α, ρ, and β. For one thing, switch points are linear, but the preference-parameters implied by the points are not. If we make two general assumptions, we can directly calculate specific parameters from each subject's switch point.

1. If a subject's second switch point determines a specific interval of parameter values (the switch point falls between 2 and 10), we will select the midpoint from that interval.

2. If a subject's second switch point falls on a boundary (the switch point is 1 or 11), we will take the exact value associated with that boundary.

[21]Our supplemental materials provide regression analysis of a subject's switch point (in the first 10 decisions of a task) in each of the three tasks and the choice of early resolution in the uncertainty-resolution elicitation task on psychological tests scores and personal characteristics. With the exception of males who tend to be more risk seeking and prefer early resolution less often, these results hold generally within our subject pool and do not seem to be correlated with a specific demographic or psychological type.

Our supplemental materials provide additional details on how each parameter was calculated.

Figures 8(a–c) show histograms of subject preferences determined entirely from the second switch point. Note that α is determined entirely from the second switch point in the risk-preference task, while β and ρ are obtained solving a system of equations involving both the second switch point in the time-preference and intertemporal-substitution-preference elicitation tasks. Note that β values appear much more well-behaved ($\beta \approx 1$) than implied in Table 2. This is because the β is determined from responses in both the time-preference and intertemporal-substitution-preference elicitation tasks accounting for the curvature of subject utility as well as time preference. (Recall that Frederick et al., 2002, mention that controlling for the curvature of utility reduces estimated subject discount rates.)

Figures 9(a–c) provide scatterplots of the correlation between the α, β and ρ parameters determined from the second switch point. The points are labeled to indicated the subjects' choice on the uncertainty resolution task. The correlation between α and β in Figure 9a is slightly negative (-0.1714), this relationship is negative among to early-resolution preferring (-0.1306), late-resolution preferring (-0.3004), and indifferent (-0.2817) subjects. Figure 9b shows the relationship between subject values of β and ρ, there is a more pronounced negative correlation (-0.8558) which is found among all subject types (-0.8461, early, -0.9999, late, -0.8826, indifferent). Figure 9c shows the relationship between subject values of α and ρ. The values have a very slight correlation (0.0331) which varies among subject types (-0.0358, early, 0.3099, late, 0.1170, indifferent).

Figure 10 provides the same information as Figure 9c shown against the identity line. Following the predictions of Epstein and Zin, subjects with estimated $\alpha < \rho$ should prefer early resolution. Subjects with $\alpha > \rho$ should prefer late resolution and those with $\rho \approx \alpha$ be indifferent. The figure shows some support for this prediction. There are 11 points above the identity line, representing subjects with estimated $\alpha > \rho$. There are 90 points below the identity line, representing subjects with estimated $\alpha < \rho$. Of the 11 subjects above the line, 4 (36%) prefer early resolution. Of the 90 subjects below the identity line, 56 (62%) prefer early resolution. This finding is only suggestive; Fisher's exact test reveals little significance to the differences between the groups (p-values: 0.115 and 0.094, 1-sided). Granted these parameters were developed for illustrative purposes only, not to directly test a model, so we should not weigh this result heavily. We use a structural, finite mixture model and regression analysis to properly test our model in the next section.

5.3 A finite mixture model for subject preference

Our summary estimates provide initial, suggestive evidence for a correlation between risk-preference parameters, intertemporal-substitution-preference parameters, and preference of uncertainty resolution in the way suggested by theory. However, the parameter estimates used in that decision were based on subject second switch points and did not take into account subject error or parameters outside the implied boundaries of the tasks. Further, subjects in our population may be categorized into certain types. For these reasons we follow the pioneering work of Stahl and Wilson (1995) and Bruhin et al. (2010), among others, and use a finite mixture model to classify subject preferences into distinct groups. We then test the Epstein-Zin model's predictions by examining the relation between the probability a subject falls into a group predicted to prefer

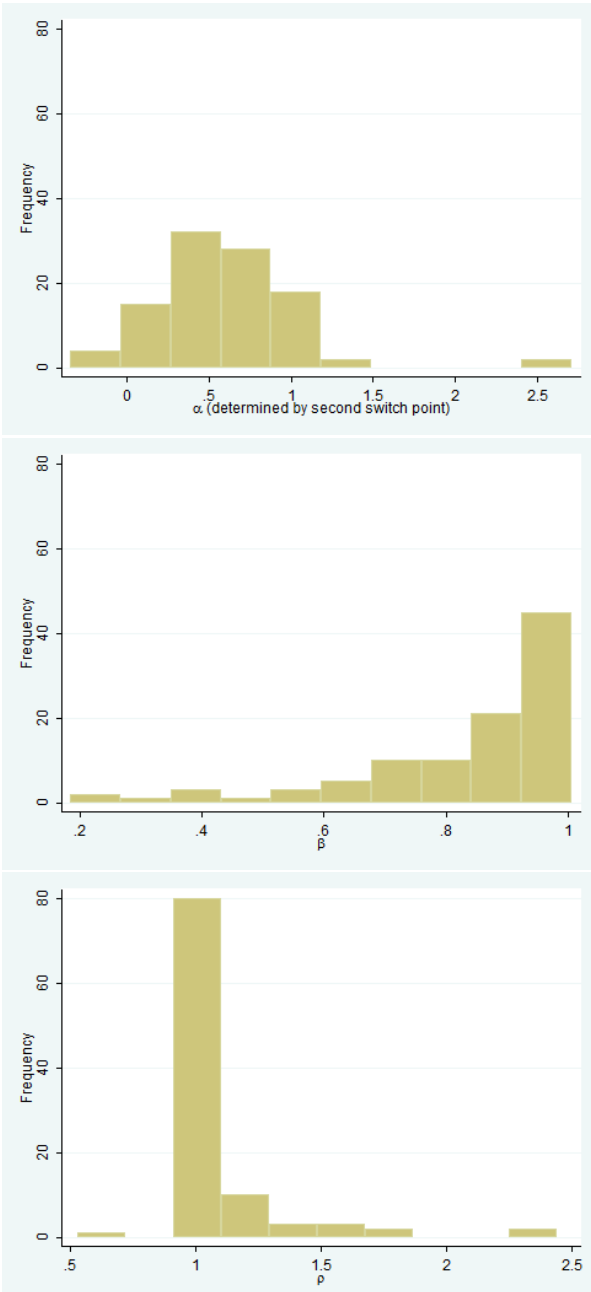


Figure 8: Histograms of subject parameter values determined entirely from second switch points. (a, top): α values determined by second switch point in risk-preference elicitation task. (b, middle): β values determined from second switch points in time-preference and intertemporal-substitution-preference elicitation tasks. (c, bottom): ρ values determined from second switch point in time-preference and intertemporal-substitution-preference elicitation tasks.

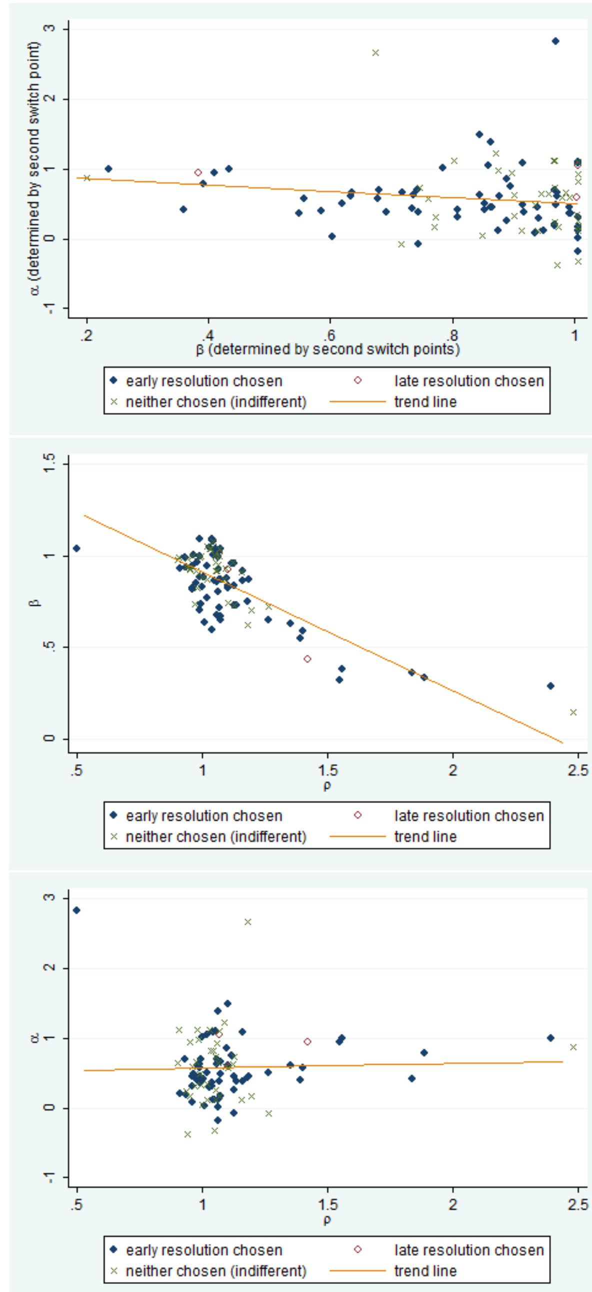


Figure 9: Scatterplots of subject parameter values determined entirely from second switch points. Choice in uncertainty-resolution-preference elicitation task is also indicated. (a, top): scatterplot of risk-preference parameter (α) and time-preference parameter (β) values ($r = -0.1714$). (b, middle): scatterplot of time-preference parameter (β) and intertemporal-substitution-preference parameter (ρ) values ($r = -0.8558$). (c, bottom): scatterplot of risk-preference parameter (α) and intertemporal-substitution-preference parameter (ρ) values ($r = 0.0331$).

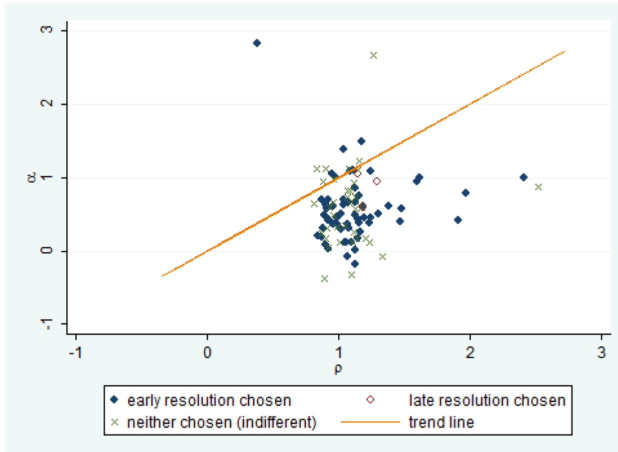


Figure 10: Scatterplot of α values determined by second switch point in risk-preference elicitation task and ρ values determined from second switch points in time-preference and intertemporal-substitution-preference elicitation tasks against identity line. Epstein-Zin theory predicts subjects with values above the line ($\alpha > \rho$) should prefer late resolution and those below the line $\alpha < \rho$ should prefer early resolution. Of the 11 subjects above the line, 4 (36%) prefer early resolution. Of the 90 subjects below the identity line, 56 (62%) prefer early resolution.

early resolution (or late resolution, or to be indifferent) and the actual choices made on the uncertainty-resolution-preference elicitation task by that subject.

A subject ($i \in N$) makes on a decision ($j \in J$) in the risk-preference, time-preference, and intertemporal-substitution-preference elicitation tasks based on the relevant parameters α, β and ρ. Define $\theta = (\alpha, \beta, \rho)$ Let $u_{ij}(\theta)$ be the utility subject i receives from choosing Option A on decision j. Let $u'_{ij}(\theta)$ be the utility subject i receives from choosing the Option B on decision j. Utility on each task is determined equation 6. Error term ϵ_j represents subjects' idiosyncratic preferences over choice j. We assume this term is private information known to the subject and independently and identically distributed from a logistic distribution (e.g., McFadden, 1974). Thus in choice j a subject will choose the Option A over Option B when $u_{ij}(\theta) > u'_{ij}(\theta) + \epsilon_j$. This will occur with probability

$$p_{ij}(\theta) = \frac{\exp[u_{ij}(\theta)]}{\exp[u_{ij}(\theta)] + \exp[u'_{ij}(\theta)]}. \tag{7}$$

Let $x_{ij} = 1$ if subject i chooses the Option A at choice j and $x_{ij} = 0$ if subject i chooses the Option B instead. Given θ, the probability that a subject j will make his observed choices is

$$f(x_i|\theta) = \prod_{j=1}^{J} x_{ij}p_{ij} + (1 - x_{ij})(1 - p_{ij}). \tag{8}$$

A finite mixture models supposes there are C general types in the population corresponding to parameter types $\theta_1, \ldots, \theta_c, \ldots, \theta_C$. The proportion of the population with parameters θ_c is π_c where $\sum_{c=1}^{C} \pi_c = 1$.

For any finite mixture model defined by C, $\pi_1 \dots \pi_C$, and $\theta_1 \dots \theta_C$ the likelihood is

$$L(\pi_1 \dots \pi_C, \theta_1 \dots \theta_C) = \prod_{i=1}^{N} \sum_{c=1}^{C} \pi_c f(x_i|\theta_c). \tag{9}$$

As Bruhin et al. (2010) note, the literature provides little guidance in determining the proper value of C, the number of types, in finite mixture models. An approach they advocate is to "use one's central research question as a guideline (p. 1388)." The model we are testing has three possibilities for agents, those with parameters $\alpha < \rho$, $\alpha > \rho$ and $\alpha = \rho$, respectively. The latter type corresponding to traditional expected utility theory. For this reason, it makes sense for our finite mixture model to have *at least* three types, restricted to the three ranges of parameters. If we do have more than three types a natural split may be to have a type with a very high ρ. As we observe in the intertemporal-substitution-preference elicitation task, nearly half our subjects do not ever switch to Option B. These subjects likely will be classified as $\alpha < \rho$ but may be different from the other subjects classified with that classification, who did switch in the task. This leads us to believe four types may be more appropriate than three.

We use a modified version of the EM-algorithm to maximize equation 9 in the cases of $C = 3$ and $C = 4$ respectively.We restrict the data to have a least one type where $\alpha < \rho$, $\alpha > \rho$ and $\alpha = \rho$. Table 4 provides results of our four type case (see our supplemental materials for our three type model). We include calculations of four different criteria (Akaike information criterion, AIC, Bayesian information criterion, BIC, normalized entropy criterion, NEC, and integrated completed likelihood condition, ICL) for evaluating the fit of finite mixture models. On each of the criteria the lowest value should be preferred. The fact that $NEC < 1$ for both models indicates they fit the data better than a single parameter model ($C = 1$) (Biernacki et al., 1999). Three of the four criteria are lower for the $C = 4$ classification, one is lower for the $C = 3$. In light of this data, we prefer the $C = 4$ classification, largely because it separates the $\alpha < \rho$ group into two types: those with very high ρ and those without. We believe this classification captures the disparate subject responses we observed on the intertemporal-substitution-preference elicitation task.

The model shows many of the same tendencies found in our preliminary look at parameters in Section 5.2. Most subjects are classified as having $\alpha < \rho$ (68% are either types 3 or 4). The type restricted to have $\alpha > \rho$ (type 2) reaches its boundary, and effectively can be thought as being $\alpha = \rho$. With this interpretation we conclude that roughly one third of our subjects can be classified as fitting a type consistent with the assumptions of standard expected utility models in regards to risk and intertemporal-substitution preference parameters. The other two thirds have intertemporal-substitution-preference parameters (ρ) greater than risk-preference parameters (α), a type predicted by Epstein-Zin theory to prefer early resolution.

From the classification of our mixture models we can calculate posteriors—the probability that any subject would be a certain type in the model.[22] We then can examine whether the probability of being a early-resolution preferring type (one with $\alpha < \rho$) is correlated with a choice of early resolution on the uncertainty-resolution-preference elicitation task. We use the $C = 4$ model and add the posteriors of a subject falling into either of the early preferring groups (types 3 and 4). We regress this on the choice a subject made on the

[22]As the histograms in our supplemental materials show, these probabilities are well-defined (close to 0 or 1) for nearly all subjects for each of the four types.

type (restriction)	proportion of type (π_c)	time-preference parameter (β)	risk-preference parameter (α)	intertemporal-substitution-preference parameter (ρ)
1 (ρ=α)	0.235 (0.087)	0.935 (0.228)	0.996 (0.369)	0.996 -
2 (α>ρ)	0.069 (0.065)	0.393 (0.214)	1.225 (0.229)	1.225 (0.170)
3 (α<ρ)	0.407 (0.111)	1.000 (0.282)	0.202 (0.128)	3.002 (66.464)
4 (free)	0.288 (0.109)	0.581 (0.196)	0.290 (0.196)	1.575 (18.283)

Table 4: Finite-mixture-model classification with four types ($C = 4$) of 101 subjects. Parameters are restricted within each type. Standard errors are estimated by 1000 bootstraps of subject data. Akaike information criterion (AIC), Bayesian information criterion, (BIC), normalized entropy criterion (NEC), and integrated completed likelihood condition (ICL) are 5534.2, 5628.1, 0.007, 5138.2, respectively. The log likelihood of the model is -2753.1. See our supplemental materials for histograms of subject posterior probabilities for each of the four types.

uncertainty-resolution-preference elicitation task (early preference=1, any other choice=0) to create a linear probability model.

One issue with this approach is that the posterior probability of being in an early-preferring group is an estimated quantity. Thus the x-terms in our regression are not exact and contain errors. This is known as an error-in-variables problem. To address this issue, we use the Higher-Order-Moments approach of Erickson and Whited (2000, 2002, 2012) to account for the estimated quantities in our regression. Table 5 provides the results of both regressions.[23]

The two regressions in Table 5 provide support for the general correlation of preferences within Epstein-Zin theory. The first regression suggests a subject completely classified as being a type 3 or 4 (those types with $\alpha < \rho$) chooses early resolution with 20% more probability in the uncertainty-resolution-preference elicitation task (two-tailed p-value < 0.1) over subjects completely classified as being a type 1 or 2 (those types with $\alpha = \rho$). When we control for the error-in-variables problem—the fact our regressors are estimated quantities—using the higher-order-moments method of Erickson and Whited, we find a dramatic increase in the sign and significance of this relation. Subjects completely classified as early-preferring types choose the early option with 50% more probability (two-tailed p-value < 0.01) than those classified as indifferent types.

[23] A logit or probit specification does not alter levels of significance in the first regression. In the second regression, the Erickson-Whited Higher-Order-Moments approach requires a linear model, so we were unable to compare results across specifications.

dependent variable:	Uncertainty-resolution-preference elicitation task, early resolution chosen	Uncertainty-resolution-preference elicitation task, early resolution chosen
posterior probability of being in an early-prefering group, finite mixture model (C=4)	0.201* (0.108)	0.507*** (0.014)
constant	0.454*** (0.089)	0.241*** (0.050)
Type of regression?	linear	Erickson-Whited Higher-Order-Moments
observations	101	101
R^2	0.034	-

* Significant at the 10% level
** Significant at the 5% level
*** Significant at the 1% level

Table 5: Regressions of subject choice of early resolution in uncertainty-resolution elicitation task on combined posterior probability of being in an early resolution preferring group in four type ($C = 4$) finite mixture model (see Table 4). Linear probability models used.

6 Conclusion

Numerous studies adopt recursive preferences such as the Epstein-Zin model to describe the market discount factor that reflects financial investors' attitudes toward risk, uncertainty and time. Are these preferences consistent with individual behaviors? This paper attempts to answer this important question. While not the first paper to examine these preferences individually, this paper provides the first examination of the correlation of preferences of uncertainty resolution with risk, time and intertemporal-substitution preferences, with the intent of testing the predictions of Epstein and Zin. As a consequence, the experiment also investigates the validity of several assumptions of a standard expected utility model with power utility functions. Contrary to the assumptions of that model, estimated subject parameters for risk preference and intertemporal-substitution preference are different for roughly two-thirds of subjects. All are classified as having the the risk-preference parameter (α) less than the intertemporal-substitution-preference parameter (ρ). The other one-third of subjects fit a type consistent with parameters with standard expected utility models ($\alpha = \rho$).

Under these conditions, the Epstein-Zin model would predict that two-thirds of subjects would prefer early resolution of uncertainty and none would prefer late. The fourth task in this experiment provides an incentivized way for subjects to reveal their preference for the resolution of uncertainty. The results show—consistent with other studies on this topic, but contrary to the predictions of expected utility theory—62% of subjects have a preference for the resolution of uncertainty; 60% prefer early resolution and 2% prefer late.

To better test the predictions of the Epstein-Zin model, this paper investigates the correlation with being classified a type that should prefer early resolution ($\alpha < \rho$) and a subject's choice on the uncertainty-resolution-preference elicitation task. Our regression results suggest this relation is positive and significant. A linear probability model predicts a 20% increase in choosing early resolution if a subject is classified as an early preferring type. Controlling for the error-in-variables problem in this model we find this number increases to 50%. Thus this paper provides evidence of a correlation between preferences of risk and intertemporal-substitution and a preference for uncertainty resolution in direction the Epstein-Zin model predicts. Since no subjects were classified as those who should prefer late-resolution, and only three subjects chose late resolution, a similar conclusion cannot be drawn for late resolution.

Future extensions may examine the robustness of our main result. We use an undergraduate subject pool; it would be useful to see if these results hold with a subject pool typically active in financial markets.[24] Expanding the time horizon and using higher stakes could conceivably alter preferences for risk, time, intertemporal substitution and uncertainty resolution in various ways.[25] All our payoffs are gains, and using losses might cause subjects to appear more risk-seeking and more often prefer late resolution.[26]

The results of these extensions notwithstanding, our findings suggest individuals consider risk, intertemporal smoothing, and dynamic uncertainty in an interactive way. Given that the attitudes toward risk, time and intertemporal substitution have implications on strategic asset allocation of investors, the results imply a potential link between individual portfolio choice problems and early resolution of uncertainty. It is intuitive to infer that investors with preference on the early resolution of uncertainty demand a smaller portion of risky assets, if the uncertainty in the risky assets is slowly unraveling. Indeed, our appendix theoretically illustrates that this is the case, and the hedging demand term of optimal allocation (e.g., Merton, 1971) is associated with uncertainty resolution as well as conventional risk aversion. Studying this in an empirical or experimental setting can be a challenging yet rewarding task, which is left as a future project.

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[24]von Gaudecker et al. (2012) examine selection effects in risk-preference elicitation by comparing samples restricted to those recruited from a Dutch university to an entire city population. Non-students make more errors in choices, but the average elicited values for risk-preference do not change across populations.

[25]Numerous studies have examined our four preferences under different time-horizons and stakes. As we mentioned previously, with the exception of time-preference (where differences over stakes and time horizon are highly correlated, see Eckel et al., 2005), our preference results are largely consistent with other studies using high stakes and longer time horizons. Thus, using higher stakes and longer time horizons will likely increase our estimated β. Though it may not affect subject type classification or our main results, because our other estimations would likely remain similar.

[26]Using hypothetical questions, Kahneman and Tversky (1979) find evidence of greater risk-seeking in the domain of losses; Chew and Ho (1994) and Ahlbrecht and Weber (1997) do not find large differences in uncertainty resolution preference across gains and losses.

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A Implications for financial decision making

It is well known that financial investors determine their portfolios depending on the size of risks, and how the sources of risks evolve over time. Typically, high (low) risk aversion leads to a smaller (bigger) portion of wealth invested in risky assets, and a high (low) elasticity of intertemporal substitution dictates an investor's willingness (reluctance) to tilt her consumption profile. A natural question is if this uncertainty resolution plays a role in determining investors' resource allocation toward risky assets. To analyze this, an investor's decision problem equipped with Epstein-Zin preferences and its implications on asset allocations and asset prices are given below. As before, it is assumed that the individual has recursive preferences of

$$V_t = \left[(1-\beta)C_t^{\rho} + \beta\left(E_t V_{t+1}^{\alpha}\right)^{\frac{\rho}{\alpha}}\right]^{\frac{1}{\rho}}, \tag{6}$$

where the elasticity of intertemporal substitution is $1/(1-\rho)$ and relative risk aversion is $(1-\alpha)$. An infinite number of periods are assumed. Then the individual maximizes the preference function subject to the budget constraint,

$$W_{t+1} = R_{w,t+1}(W_t - C_t),$$

in which W_t is the total wealth at the beginning of time t and $R_{w,t+1}$ is the return on wealth defined by

$$\begin{aligned} R_{w,t+1} &= \phi_t(R_{t+1} - R_f) + R_f, \\ R_t &= \exp(r_t), \\ R_f &= \exp(r_f), \end{aligned}$$

where r_t is the one-period log return on the risky asset, ϕ_t is the proportion of total wealth invested in the risky asset at time t, and r_f is the one-period return on the risk-free asset. Furthermore, it is assumed that

$$\begin{aligned} r_{t+1} &= E_t r_{t+1} + \sigma_t^r u_{t+1}, \\ x_t &= E_t r_{t+1} - r_f, \\ x_{t+1} &= \mu + \eta_x(x_t - \mu) + \sigma_t^x \epsilon_{t+1}, \end{aligned}$$

where $u_t, \epsilon_t \sim N(0,1)$ and $corr(u_t, \epsilon_t) = \xi_{u\epsilon}$.

Then, it can easily be shown that the optimal weight for risky asset is

$$\phi_t = \frac{x_t}{(1-\alpha)(\sigma_t^r)^2} + \frac{1}{2(1-\alpha)} - \frac{\alpha}{(1-\alpha)} \frac{(1-\rho)}{\rho} \frac{\mathrm{cov}_t(u_{t+1}, c_{t+1} - w_{t+1})}{\sqrt{\sigma_t^r}}$$

if volatility terms are constant.[27] As one can see, in addition to the conventional myopic asset demand represented by the first and second terms, there is a hedging demand which depends on future consumption and portfolio decisions. This term states that the investor will hold more of the risky asset if future returns from the risky asset co-vary negatively with the future consumption-wealth ratio (i.e., hedging demand). Of course, this component is not exogenous because $c_{t+1} - w_{t+1}$ is endogenously determined. In fact, Campbell and Viceira (1999) linearly approximate the logarithm of the budget constraint to solve for the optimal portfolio weight and the consumption-wealth ratio. To illustrate their finding, their approximation is inserted into the above equation to obtain

$$\phi_t \approx \frac{x_t}{(1-\alpha)(\sigma_t^r)^2} + \frac{1}{2(1-\alpha)} + \frac{\alpha}{(1-\alpha)} \frac{\sum_{j=1}^{\infty} \theta^j \,\mathrm{cov}(u_{t+1}, E_{t+1} r_{w,t+j})}{\sqrt{\sigma_t^r}}$$

where $\theta = 1 - \exp(\overline{c-w})$, and this is the case with no time-varying and stochastic volatility. Again, this is an incomplete solution, but this approximated version says that only risk aversion directly affects the demand for the risky asset as the weight between myopic demand and hedging demand. Elasticity of intertemporal substitution only indirectly affects the demand via θ according to Campbell and Viceira (1999).

However, this is somewhat puzzling because the existence of uncertainty resolution can influence the demand for the risky asset, and uncertainty resolution is related to both risk aversion and elasticity of intertemporal substitution under this recursive preference. Given that the resolution of uncertainty is about preference ordering on higher-order moments of random lotteries, second-order approximations to the above problem can shed light on this issue. To this end, the optimal portfolio weight for risky assets is approximated using a second-order approximation.

$$\phi_t \approx \frac{x_t}{(1-\alpha)(\sigma_t^r)^2} + \frac{1}{2(1-\alpha)} + \frac{\alpha}{1-\alpha} \frac{\frac{\chi}{2} \sum_{j=1}^{\infty} \varphi^j E_t \left[e^{\left(\frac{\rho}{1-\rho} E_{t+j} r_{w,t+j+1} + \frac{\alpha(1-\rho)}{2\rho} \sigma_t^r \right)} \right] \mathrm{cov}_t(u_{t+1}, r_{w,t+j})}{\sqrt{\sigma_t^r}}$$

where φ is a coefficient resulting from the approximation.[28]

Now, the hedging demand term has both α and ρ parameters, and the related term has long-term effects. Combining with this paper's results, this states that risk aversion plays a role of weighting between myopic demand and hedging demand, whereas the preferences on intertemporal substitution work through the conditional expectation of long-run performances of the wealth portfolio via the channel of uncertainty resolution. That is, if the expected values and volatility of returns on risky assets vary over time such that

[27] A general version of this result with time-varying and stochastic volatility is available in this paper's supplemental materials. While it is beyond the scope of our paper, it will be interesting to study implications of an asset allocation problem considering skewness and kurtosis of asset returns as well.

[28] For a derivation with stochastic volatility see our supplemental materials.

the uncertainty in the financial market is gradually resolved, the optimal portion of risky assets is affected by both preferences of risk aversion and intertemporal substitution. In particular, this effect prevails via the following terms:

$$E_t \left[\exp \left(\frac{\rho}{1-\rho} E_{t+j} r_{w,t+j+1} + \frac{\alpha(1-\rho)}{2\rho} \sigma^r_{t+j+1} \right) \right],$$

where $j = 1, 2, 3, \ldots$. Suppose that an investor is risk averse with relative risk aversion of 2, (i.e., $\alpha = -1$). Then, one can easily see that higher intertemporal substitution (higher values of ρ) increases the size of this term, which leads to a lower fraction of the risky asset that co-varies with the returns from the investor's wealth $(i.e., Cov_t(u_{t+1}, r_{w,t+1}) > 0)$.[29] This paper's results state that a majority of subjects prefer early resolution implying a high intertemporal substitution. Therefore, it is inferred that average investors tend to invest less in risky assets if they prefer early resolution. This is, in fact, an important issue in the literature of asset allocation because most models generate a counterfactual implication that investors hold an excessive amount of risky assets contrary to empirical regularity that most investors hold only a small amount of risky assets, referred to as the portfolio allocation puzzle.[30] In sum, the theory suggests that investors hold less risky assets provided that they prefer early resolution of uncertainty, and our experimental results confirm that most subjects chose early resolution of uncertainty.

[29] If risk aversion is mild, for instance, $0 < \alpha < 1$, the sign of $\frac{\alpha}{1-\alpha}$ becomes positive, and higher intertemporal substitution reduces risky asset holding from future return volatilities, while increasing the future expected returns in the same case. Hence the overall effect is a quantitative concern.

[30] A related but different issue is the limited participation in asset markets. This describes a phenomenon that only a fraction of people actually hold and trade assets, which refers to an extensive margin in a financial decision. Limited participation in stock markets can result from limited access to loan markets, lack of knowledge or information on financial markets, participation costs, and other market frictions. In a sense, the existence of limited participation helps justify our result that investors are sophisticated enough to take into account uncertainty resolution as well as risk aversion and intertemporal substitution, because those who enter into investing are likely to overcome the entry barriers, hence consider various aspects of preferences in making decisions under uncertainty.