On the Evolutionary Origin of Prospect Theory Preferences

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Prospect theory scholars have identified important human decision-making biases, but they have been conspicuously silent on the question of the origin of these biases. Here we create a model that shows preferences consistent with prospect theory may have an origin in evolutionary psychology. Specifically, we derive a model from risk-sensitive optimal foraging theory to generate an explanation for the origin and function of context-dependent risk aversion and risk-seeking behavior. Although this model suggests that human cognitive architecture evolved to solve particular adaptive problems related to finding sufficient food resources to survive, we argue that this same architecture persists and is utilized in other survival-related decisions that are critical to understanding political outcomes. In particular, we identify important departures from standard results when we incorporate prospect theory into theories of spatial voting and legislator behavior, international bargaining and conflict, and economic development and reform.

Prospect theory has become one of the most influential behavioral theories of choice in the wider social sciences, particularly in psychology and economics (Kahneman, Slovic, and Tversky 1982; Kahneman and Tversky 1979). It has also been applied to issues in political science (Druckman 2001; Lau and Redlawsk 2001; McDermott 2004; Mercer, 2005; Quattrone and Tversky 1988); in particular, in the areas of international relations (Berejikian 1997, 2002; Faber 1990; Jervis 1994, 2004; Levy 1994, 1997; McDermott 1998), international political economy (Elms 2004), comparative politics (Weyland 1996, 1998), American politics (Patty 2006), and public policy (McDaniel and Sistrunk 1991). As a model explaining decision making under conditions of risk, prospect theory provides an elegant description of the relationship between environmental contingency in the form of gains and losses and individual risk propensity. In short, those faced with gains tend to be risk averse, while those confronting losses become much more risk seeking. Prospect theory developed in explicit opposition to more normative models of rational choice, such as subjective expected utility theory.

Historically, prospect theory also evolved in reaction to earlier behavioral models exemplified by figures such as B.F. Skinner (1952) who wholly disregarded the importance of cognitive processing in human action. As such, prospect theory can be understood as representing the apex of the cognitive revolution in psychology and social sciences in general (Simon 1985). This historical development of prospect theory as a significant departure from behavioral into cognitive explanations for decision making is interesting because, as Mercer notes; "The dominant explanation for political scientists' tepid response focuses on the theoretical problems with extending a theory devised in the lab to explain political decisions in the field . . . .It suggests that prospect theory's failure to ignite the imagination of more political scientists probably results from their aversion to behavioral assumptions and not from problems unique to prospect theory" (2005, 1). And, indeed, more recent work in decision making within cognitive neuroscience has also begun to incorporate emotion and motivation into cognitively oriented theories of choice. Similar research trends can be observed in economics as well (Andreoni 1990; Bolton and Ockenfels 2000; Dawes et al. 2007; Fehr and Schmidt 1999; Rabin 1993, 2002).

Models derived from risk-sensitive optimal foraging theory offer an opportunity to generate an

explanation for the origin of the risk propensities described by prospect theory. Certainly, psychologists such as Gigerenzer (1996) and Cosmides and Tooby (1996), among others, endorse an evolutionarily informed alternative perspective on the origin and function of human decision-making biases. Our particular evolutionary model provides a parsimonious explanation for why individuals may possess hardwired tendencies to make choices consistent with the predictions of prospect theory. Although this model suggests that human cognitive architecture evolved to solve particular adaptive problems related to finding sufficient food resources to survive, we argue that this same architecture persists and is utilized in other survival-related decisions.

An evolutionary model for the origin of prospect theory preferences holds significant implications for understanding the nature and function of human decision-making processes. This matters because intervention is less likely to be successful in changing these risk predilections. For example, cognitive biases, and other lapses from rationality, can be at least partially remedied with sufficient learning, awareness, and education. This can take place through experience, Bayesian updating, or other processes. While such biases may always have the characteristic quality of visual illusions in that people can "feel" the pull of framing effects even when they are made transparent, individuals can adopt strategies to overcome their more negative tendencies. However, if prospect theoretic tendencies concerning risk propensity lie more deeply rooted in human evolutionary psychology, the implications for decision making and potential remediation shift. First, such biases may not be so easily overcome, particularly with individuals who live close to the margin of survival. Second, people may prove less likely to be able to learn over time or through experience to compensate for these tendencies. And finally, politicians and others may be able to manipulate humans for their own means by invoking such modules, for example by emphasizing emotional threats to survival to order to increase support for risky policies.

We argue for a greater sensitivity to *ecological rationality* in models of politics. How a person thinks, and what constitutes rational behavior, depends on the situational and environmental context in which that individual operates. An ecologically valid model of political behavior, or any other behavior, involves an interaction between both individual characteristics and specific situational aspects of the environment. Being hungry provokes different thoughts, feelings, and behaviors than being full, just as being wealthy, white, and male produces different options, expect-ations, and choices than being poor, black, and female. Behavior results from the person acting within the context of a situation; both disposition and situation determine outcome, and neither should be left out of the equation in service of parsimony or simplicity.

Prospect Theory

Daniel Kahneman won the Nobel Prize in Economics in 2002 for his work with Amos Tversky on prospect theory. This model proved widely influential because it provided comprehensive empirical demonstrations of actual human decision-making behavior in risky domains. This theory contradicted many of the assumptions and implications of standard economic theory, thereby spawning a great deal of research in behavioral economics designed to examine "anomalies" in choice.

Briefly, prospect theory comprises two phases, the editing phase, which constitutes framing effects, and the evaluation phase. Framing effects demonstrate, for example, that people make substantively different choices when confronting alternate outcome framings (Tversky and Kahneman 1981). Most famously, people make different choices about medical treatment when options are phrased in terms of "survival" or "mortality," even when the objective outcome probabilities remain identical. Specifically, people are much more risk averse in the "gain frame" when outcomes are expressed in terms of the probability of living (survival), than in the "loss frame" when outcomes are expressed in terms of the probability of dying (mortality) (McNeil, Sox, and Tversky 1982).

The evaluation phase incorporates a value function and a weighting function. The value function predicts risk aversion in the domain of gains and risk taking in losses. Importantly, gains and losses are evaluated relative to a reference point, often assumed to be equivalent to the status quo, but which in reality can deviate from this point in response to such factors as social comparison, current need state, future expectations, or past history. The weighting function establishes a nonlinear decision weight independent of normative probability. This function demonstrates that individuals tend to overweight small probability events while underweighting medium and high probability events. Interestingly, people overweight certainty, such that they tend to treat highly probable events as certain and highly improbable events as if they are impossible.

Several findings prove quite robust experimentally, including framing effects, shifts in risk propensity based on domain, and loss aversion, meaning that losses hurt more than equal gains please. Tversky argued that this model was intuitively supported by the psychophysics of happiness; it is easy to make someone miserable for a long time, but quite hard to make anyone happy for even a brief period. The "Hedonic Treadmill" (Brickman and Campbell 1971) is a perfect example of this phenomenon; people have to work harder and harder just to maintain the same level of happiness. Because human attention evolved to focus on change as opposed to stasis, individuals remain most sensitive to change that threatens to make things worse.

In fact, asymmetry in the hedonic experience of gains and losses can be understood intuitively from this evolutionary perspective as well. Outside the realms of reproduction and eating, few positive experiences offer fitness advantage. After all, in the end, there are natural limits on reproduction and raising offspring, which are higher for women than men, since the length of pregnancy places limits on the number of children a woman can bear. But surviving or avoiding even a single negative experience resulting from encounters with predators or poisoned food may prove essential for survival and fitness. In other words, when survival is uncertain, marginal losses prove more critical for reproductive success than marginal gains. As Aktipis and Kurzban (2004) note, a hungry animal should be more motivated, and thus risk taking, to find food, than a full one. That is why, as they argue, the first doughnut always tastes better than the fifth, a phenomenon akin to those experienced by coffee and tobacco addicts.

Indeed, some have questioned whether individuals display such strong framing effects with regard to money as they do in the arena of human lives, assuming that most people value the latter more than the former. In one study (Fagley and Miller 1997), subjects made riskier choices in the domain of human life than in the financial realm, regardless of whether that choice was in gains or losses. However, a notable sex difference appeared in this study, indicating that women's choices were affected by frame, while men's choices were not. The authors provide no explanation for their findings, but this sex difference may simply reflect the location of the salient reference point across genders. For example, Shane Frederick argued that smarter people appeared to be more risk acceptant in general, while men prove more risk acceptant than women, even controlling for intelligence. He writes, "(e)xpressed loosely, being smart makes women patient and men take more risks" (2005, 38).

Sex differences in this area can be explained by different evolutionary motives and pressures as well; women are more likely to pass on their genes if they provide nurturance and protection for their children, while men often have to fight challengers for access to reproductive rights from the outset. Individuals would thus be expected to vary predictably in their individual risk curves if their current state, starvation or satiation, determines whether the survival of their genes is at stake. In other words, individuals in different hedonic states, happy or sad, hungry or full, may demonstrate the same prospect theory shaped curve, albeit with different reference points based on a transient current state (Aktipis and Kurzban 2004).

From an evolutionary perspective, we would expect decisions over life and death matters to demonstrate greater consistency with prospect oriented preferences than choices involving money. If such risk propensities evolved in the context of choices that affect survival, the cues which trigger them would most likely be elicited in similar contexts. Further, we might expect systematic sex differences in basic risk propensity, reflected by different average reference points experienced by men and women; women, requiring greater protection during pregnancy and later for protecting vulnerable offspring, would likely have lower starting reference points than men, on average, leading to greater caution in survival-related circumstances. Again, circumstances dictate the context of individual choice and structure the cues which trigger either risk-seeking or risk-averse behavior; the genetic costs for women abandoning offspring are simply much higher than they are for men, inducing greater caution in environments of uncertainty, whereas men may benefit reproductively by taking chances to find and win mates.

Risk-Sensitive Optimal Foraging Theory

Employing a theoretical evolutionary perspective helps provide a consistent explanation for human decision making which, while often appearing consistent with some elements of standard economic theory, deviates systematically and predictably within risky contexts in the ways expected by prospect theory. Importantly, an evolutionary perspective posits that humans evolved specific cognitive mechanisms that

were selected over time to respond to the adaptive challenges repeatedly faced by our hunter-gatherer ancestors (Barkow, Cosmides, and Tooby 1992).

Specifically, humans evolved a variety of innate programs designed to solve particular problems, such as language acquisition. These programs are domain specific and content laden. The skills and strategies humans use differ by task: acquiring language requires different skills and abilities than learning math; linguists like Chomsky (1956) and Fitch, Hansen, and Chomsky (2005) have shown that mathematical laws applied to language acquisition fail to account for the speed, accuracy, and universal fluency achieved by all normal young children. Similarly, particular domains contain very specific content. For example, vision has very specific content which allow us to maintain color constancy over the course of changing sunlight across the day. The information our eyes process is not at all what we experience ourselves as "seeing" and yet our brains "see" the same thing (say "green grass") over the course of the day although the light spectrum changes reliably as the earth rotates on its axis.

Often we remain unaware of our evolved programs because they operate so flawlessly, automatically, and without effort, like vision. Yet, over time, these programs can be adapted for other uses, just as reading and writing developed as by-products of our innate ability to acquire spoken language. Similarly, the cognitive hardwiring that evolved to handle risk likely evolved to solve important repeated problems which systematically affected reproductive fitness. These challenges most likely related to survival tasks, such as acquiring food and avoiding predators. Thus, in searching for a domain area in which to examine the evolutionary development of innate human risk-taking strategies, problems related to foraging for food present a promising arena. Over long periods of evolutionary time, successful strategies become universal as random genetic mutations which offer reproductive advantage become universal. Particular content laden programs are then cued by the triggers that signaled significant risk in the past. These programs, in turn, entrain specific repertoires of thoughts, feelings, and responses which conveyed reproductive success to our ancestors, but which may or may not serve us well in the current environment, which is quite different than the one in which humans originally evolved. Such programs also then become available for cooptation and adaptation in other situations and contexts that cue risk, no matter how divorced those environments may be from the original one in which they evolved. A modern example of this phenomenon can be found in drug approval; once the Food and Drug Administration approves the use of a particular drug, doctors often prescribe it "off-label" for uses far removed from their original purpose, to good or bad effect.

Around the time that Tversky and Kahneman were developing prospect theory, behavioral ecologists, ethnologists, and evolutionary biologists began questioning established views of animal behavior as well. In particular, Caraco (1980) and Stephens (1981) began challenging existing foraging models as deficient, once environmental realities, such as variation in food availability over different terrains, were taken into account. Caraco employed an expected utility model to demonstrate that animals can often benefit from a risk-taking strategy in their feeding preferences if these environmental variations prove critical to survival. Stephens (1981; Stephens and Krebs 1986) extended and formalized this notion to explain such risk sensitivity in optimal foraging, arguing that animals evolved to take advantage of variations in the probability of payoffs across various contexts.

Why was this realization important? Prior models assumed that animals would simply forage for food where the mean expected payoff was highest, independent of variance. This strategy can work effectively when food is abundant, but can risk starvation when the environment changes or remains uncertain because of seasonal weather variations. The evolutionary argument offers the important insight that animals will become most accepting of risk when their chance for starvation runs highest. Alternate feeding grounds with higher variance may present a higher risk, but they may also offer the possibility of a higher reward and provide a chance to stave off starvation. In terms of risk taking, optimal foraging models suggest that sensitivity to variance in outcome can be rational under conditions where survival is threatened. Later models sought to incorporate various trade-off calculations, as when finding more or better quality food also poses a greater risk of predators (Houston, McNamara, and Hutchinson 1993). Note the difference between this foraging strategy and that predicted by standard economic theory, which assumes that an individual should always seek out the highest expected value payoff. In many circumstances, such as when resources are abundant, it makes sense to maximize expected value and minimize risk because this strategy maximizes the probability of survival. When survival is virtually assured, standard economic theory offers good predictions for human behavior. However, the literature on prospect theory shows that when confronting loss

and death in particular, standard economic theory fails in predictable ways. In these circumstances, people do behave in ways consistent with a model based on environmental contingency, however.

Clear evidence exists that animals can demonstrate sophisticated strategies concerning risk (without being taught economic theory!). For example, Chen, Lakshminarayanan, and Santos conducted an experimental demonstration of trading behavior in capuchin monkeys. Seeking to illustrate the innate nature of decision-making biases in behavior, they showed that monkeys often appear to demonstrate clear preferences, and respond rationally to price and wealth changes, as a standard economist might suggest humans do. However, once risky choices are imposed on the capuchins, "they display several hallmark biases when faced with gambles, including reference dependence and loss-aversion" (2006, 517). The authors conclude that such demonstrations indicate the innate basis of these biases, suggesting that some evolved part of capuchin instinct is sensitive to risk and becomes increasingly risk seeking in the face of loss. Evidence from these primates suggests a common evolutionary basis for such risk propensities in humans.

In recent work designed to explain the existence of individual personality in animals, Wolf et al. (2007) examines the trade-off between early and late reproductive strategies and risk-taking behavior. Empirically, research has demonstrated that animal personality is both heritable (van Oers et al. 2005) and linked to reproductive fitness (Dingemanse and Reale, 2005), and yet remains obviously variable. Seeking to account for this conundrum, Wolf et al. argue that, "individuals with high future expectations (who have much to lose) should be more risk-averse than individuals with low expectations. This applies to all kinds of risk situations, so individuals should consistently differ in their behaviour" (2007, 581). In the words of a *Nature* writer characterizing this work, "the optimal animal should be bold only when it makes sense to be bold, and adjust its behaviour when the situation changes" (Bell 2007, 539).

Optimal foraging models also prove relevant for understanding the origins of other interesting "anomalies" in preferences that are consistent with prospect theory. For example, ambiguity aversion, whereby people prefer options with stated probabilities to those without them—even when both options hold the same expected value—can be explained from this perspective. Rode et al. (1999) suggest that people avoid unknown probabilities because they tend to co-occur with high variance in outcome.

These authors were able to reverse the ambiguity effect when the subjects' need remained greater than the expected mean outcome. When subjects were satisfied with their position, they remained risk averse and avoided the unknown probability, but when they were not satisfied, they developed a risk-seeking preference for the ambiguous option, for example. As these authors conclude, "(o)ne should not expect the cognitive architectures of evolved organisms to be "rational" when rationality is defined as adherence to a normative theory drawn from mathematics or logic. One should expect their cognitive architectures to be *ecologically rational*: well designed for solving adapted problems their ancestors faced during their evolutionary history" (Cosmides and Tooby 1994, 329; [Tooby and Cosmides 1999]).

The Model

In this section, we present a model designed to demonstrate how differences in risk propensity consistent with prospect theory predictions can offer survival advantages, thus offering a theoretical evolutionary basis for the origin of prospect-oriented preferences. Specifically, we show how factors beyond the control of the individual, such as environmental contingencies, can influence independent decisions over risk. These contingencies, in turn, can serve as environmental cues for particular patterns of risk propensity in related but independent contexts, although perhaps not as often or as strongly.

Imagine a world in which one must acquire resources in order to survive and reproduce. The easiest resource to consider is food. Suppose that in some period an individual must acquire a minimum threshold τ of food in order to live to the next period. Survival is a dichotomous variable—you are either dead or alive, you either reproduce or you do not. But resources are continuous and subject to numerous random fluctuations. For example, variation in seasonal rainfall can dramatically affect the production of fruit and nuts sought by hunter-gatherers and harvests of other foods in primitive agricultural societies. There may also be tremendous variation in the day-to-day availability of small and large game.

Suppose further that such an individual confronts a choice between a low mean, low variance source of food, and a high mean, high variance alternative source. If the person is at risk of starvation, he or she is likely to choose the high mean, high variance source precisely because it maximizes the

probability of finding enough food to survive. The low mean, low variance option may guarantee a high probability of a positive payoff, but if the expected value is low enough, the person will not survive. Thus, the person will likely take a greater risk to seek food at the high mean, high variance site because it offers the possibility of survival, however remote, that the low mean source does not. However, if the person has already acquired sufficient resources from other activities, he or she may choose the low mean, low variance site to guarantee a surplus of food above the minimum threshold. This scenario demonstrates two important factors: (1) risk propensity will depend on the current state of the decision maker, his individual reference point; (2) a switching strategy between sites can maximize survival prospects over either constant risk averse or risk seeking strategies.

We can abstract from these daily struggles with a simple assumption: the amount of food an individual acquires from the environment ϵ is a simple draw from a probability distribution. The likelihood that an individual acquires enough resources to survive is thus simply $\Pr(\epsilon > \tau)$. Suppose this is a stable probability distribution (the Normal, Cauchy, and Levy are versions of this type of probability) with mean μ and variance σ^2. Under these conditions, the probability that an individual survives is a simple standard cumulative distribution of the stable density (Φ):

$$\Phi\left(\frac{\mu - \tau}{\sigma}\right). \qquad (1)$$

Figure 1 plots the probability of survival as a function of the expected payoff μ. Notice that the relationship is not linear. When resources are very scarce ($\mu \ll \tau$) survival is unlikely and when they are very abundant ($\mu \gg \tau$), survival is virtually assured. Between these extremes is an *s*-shaped transition in which the probability bends upward as it becomes increasingly responsive to gains and then flattens out and bends downward as it approaches unity. If the payoff distribution is normal, then this curve follows a familiar probit form, but any stable probability will generate an *s*-shaped cumulative distribution. Intuitively, the figure shows that deviations from the point where the expected payoff equals the survival threshold ($\mu = \tau$) have similar effects but in opposite directions. Suppose that under these conditions the environment generates three meals in a given period. The marginal benefit of *gains* is decreasing in the size of the gain: we may not enjoy the fourth and fifth meal in a given period as much as the third meal because it has less impact on our survival. However, the marginal cost of *losses* is also

FIGURE 1 Effect of Risky and Safe Choices on the Probability of Survival in Various Environments
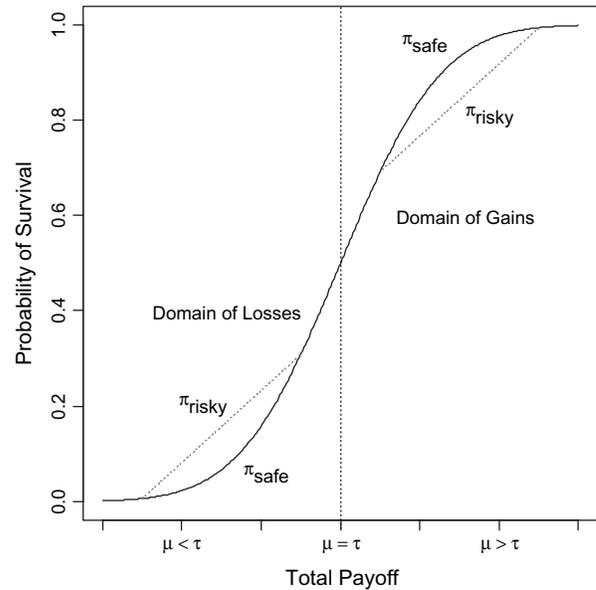
decreasing in the size of the loss: losing the third meal probably hurts much less than losing the second or first meal. At absolute starvation levels we might even be willing to risk the first meal in order to obtain enough meals to survive.

Thus, the need to attain a fixed payoff threshold to survive has consequences for choices made under risk. Suppose an individual in an environment with expected payoff μ receives both a payoff from the environment and a payoff from a decision over two alternatives. These two alternatives have the same expected value, but one is "safe" and the other is "risky"—the safe choice yields a payoff of p with probability 1. The risky choice yields a payoff of 1 with probability p and 0 otherwise. Since the expected value of each choice is the same, standard economic theory has nothing to say about it without adding an extra ad hoc assumption about risk. However, under the assumption that survival depends on achieving a minimum payoff, we can see how selection might favor certain types of individuals.

Suppose there are two types of individuals, the *bold* and the *meek*. *Bold* individuals always take the risky choice which nets them a probability of survival of

$$\pi_{risky} = p\Phi\left(\frac{\mu - \tau + 1}{\sigma}\right) + (1-p)\Phi\left(\frac{\mu - \tau}{\sigma}\right). \quad (2)$$

In other words, the probability of survival is a weighted average of the high-gain payoff (1) and the low-gain payoff (0). As p increases from 0 to 1, the expected

survival rate increases linearly from $\Phi((\mu - \tau)/\sigma)$ $\Phi((\mu - \tau + 1)/\sigma)$. In contrast, *meek* individuals always choose the safe option which nets them a sure-thing increase in their payoff. This translates into a survival probability

$$\pi_{safe} = \Phi\left(\frac{\mu - \tau + p}{\sigma}\right). \tag{3}$$

Here, p appears inside the probability of survival term because it is a certain payoff. The *meek* survival rate also increases from $\Phi((\mu - \tau)/\sigma)$ to $\Phi((\mu - \tau + 1)/\sigma)$ as p goes from 0 to 1. However, it does so nonlinearly, traveling along the contour of the s-shaped cumulative distribution function.[1] As Figure 1 shows, this means that the best-surviving strategy changes depending on the environment. In abundant environments ($\mu > \tau$) the safe choice yields a probability of survival that is higher than the risky choice for any given p. This is because the probability of survival is already high—success in the risky option does not add much to this probability, but failure substantially increases the risk of falling below the threshold. Symmetrically, when resources are scarce ($\mu > \tau$) the risky choice improves the probability of survival. When individuals have nothing to lose, it makes sense for them to engage in risky behavior with the hope that it will keep them alive through the next period.

Students of prospect theory will immediately recognize in Figure 1 the pattern of choices that have been observed in countless tests of Kahneman and Tversky's conjectures. In the "domain of gains," people typically trade reward for risk and accept the lower payoffs of the safe option. In contrast, in the "domain of losses" they are more likely to choose gambles, even when they generate expected payoffs that are lower than the safe option.

The Evolution of Prospect Preferences

We can imagine long-term changes in the abundance of resources having a profound effect on the selection of risky behavior. When times are tough, *bold* types will do better and when times are good the *meek* will fare better. If the typical variation in resources happens much faster than the pace of evolution, then species will not be able to adapt optimal behavior to each new environment. Thus, there may be a selective advantage to choice behavior that explicitly takes account of the environment when making choices. We call individuals who exhibit this kind of behavior *prospectors*. These individuals will take risks when their survival is threatened and play it safe otherwise. The more their choices conform to optimal strategies for maximizing survival, the more likely the mechanisms that evolved to generate these choices will be passed on to future generations.

This begs the question regarding what strategy is optimal. How much risk is too much? To analyze the question, suppose that an individual must acquire a payoff τ in order to survive in an environment that generates a payoff ϵ of stable random distribution with mean μ, variance σ^2, and cumulative distribution Φ. This payoff reflects the fact that there are many factors beyond the individual's control that affect his or her survival. But there are also some factors over which an individual has control. Suppose the individual additionally faces a choice Θ between a low-risk outcome θ_{safe} and a high-risk outcome θ_{risky}. Given a choice between two certain outcomes, the individual that chooses the one with higher payoff will always be more likely to survive. However, when outcomes are uncertain, the best choice is less straight-forward. Individuals must take into account the expected payoff, expected variance, and risk of each choice and also the expected payoff resulting from environmental factors over which they have no control.

To see why, suppose the payoffs from each choice $(\theta_{safe}, \theta_{risky})$ are drawn from the same stable distribution as ϵ but with different means $(\mu_{risky}, \mu_{safe})$ and variances $(\sigma^2_{risky} > \sigma^2_{safe})$. The optimal *prospector* will take the risky choice only when it generates a higher probability of survival: $\Pr(\varepsilon + \theta_{risky} > \tau) > \Pr(\varepsilon + \theta_{safe} > \tau)$.

This occurs when[2]

$$\Phi\left(\frac{\mu + \mu_{risky} - \tau}{\sqrt{\sigma^2 + \sigma^2_{risky}}}\right) > \Phi\left(\frac{\mu + \mu_{safe} - \tau}{\sqrt{\sigma^2 + \sigma^2_{safe}}}\right). \tag{4}$$

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[1]Since stable probability densities are unimodal (Yamazato 1978), Φ'' is positive before the mode, indicating it is concave up, and negative after the mode, indicating it is concave down.

[2]Consider the probability of survival with the risky choice on the left-hand side. Since both random variables are drawn from stable probabilities, they can be expressed as a single random variable with the same distribution, mean $\mu + \mu_{risky}$, and variance $\sigma^2 + \sigma^2_{risky}$. Similarly, the random variables on the right combine to form a single random variable with mean $\mu + \mu_{safe}$, and variance $\sigma^2 + \sigma^2_{safe}$.

Solving for μ produces an optimal rule for when to switch from the safe to the risky choice. The risky choice is favored when:

$$\mu < \tau - \mu_{safe} + \frac{\mu_{risky} - \mu_{safe}}{\sqrt{\frac{\sigma^2 + \sigma^2_{risky}}{\sigma^2 + \sigma^2_{safe}} - 1}} \qquad (5)$$

Intuitively, the rule specifies conditions under which an individual makes a decision in the domain of losses as opposed to the domain of gains. The rule shows that there always exists a set of conditions under which the probability of survival is improved by the risky choice.[3] It is especially important to realize that this is even true when the risky choice yields an expected payoff that is *lower* than the safe choice. Individuals in scarce environments benefit from risk because it is the only way to make it above the survival threshold, and they are even willing to trade off some expected value to acquire this risk. In economics, this kind of choice is said to have *option value*.

Suppose that the higher risk choice also yields the higher reward ($\mu_{risky} > \mu_{safe}$). First, notice that the right-hand side increases as the mean payoff from the safe outcome μ_{safe} decreases and its variance σ^2_{safe} increases. As the value of the safe option declines and becomes more uncertain, survival may be best achieved by switching to the risky option. In contrast, the right-hand side increases as the mean payoff from the risky outcome μ_{risky} increases and its variance σ^2_{risky} decreases. Safer and more rewarding risky choices will be more likely to entice *prospectors* to take a chance.

Second, the mean and variance of payoffs that are independent of the choice also affect the decision. Increasing the average expected payoff in the environment (μ) *decreases* the set of conditions that would cause a *prospector* to switch to the risky choice. In other words, as resources become more abundant, we expect individuals to become generally more risk averse. In contrast, increasing the variance of the environment σ^2 *increases* the value of the right-hand side, which makes it more likely we will observe individuals making risky choices. Uncertain environments select for individuals who choose the high-risk, high-reward option.

Third, notice that the fitness advantage of *prospectors* depends on environmental change. If μ is always high, then the *meek* will do nearly as well as *prospectors*. In fact, if *prospectors* sometimes make

mistakes because it is difficult to determine whether one is in the domain of gains or losses, then a non-contingent rule like the one used by *meek* may be superior. By symmetry, when μ is always low, *bold* types may do better than *prospectors*. Thus, we expect the greatest evolutionary pressure for the development of *prospector* preferences to occur where environments and choices keep individuals living close to the threshold of survival, or specifically where the average payoff from the environment μ is *equal to* the right-hand side in the rule above. Although such an environment may not exist in advanced industrialized countries, it seems likely to have existed in prehistoric hunter-gatherer societies and may even characterize modern-day societies where survival is difficult.

Finally, it is important to remember that we are assuming here that payoffs have an effect on the probability of *survival*. Note here that in evolutionary theory survival relates not to that of the individual, but to the survival of offspring; in other words, reproduction is critical. Individuals who find enough food will survive, but they may not reproduce. Extremely thin women, for example, have a hard time conceiving. If selection favors mechanisms that help us behave like *prospectors*, then we expect these mechanisms to have a greater effect on choices that are *fitness relevant*, that is, related to the survival of offspring. Specifically, choices about life and death, reproduction, and the survival of related individuals are all more likely to be governed by prospect preferences than other choices that have little bearing on our survival or the transmission of our genes. Although these conditions may be rare, they certainly exist in conditions of combat, famine, or other natural disasters affected by political contexts.

Political Implications

Aktipis and Kurzban (2004) have called attention to the importance of foraging theory for *economic* models of choice and decision making and here we do the same for models of politics. If human cognitive architecture evolved to respond differentially to risk in the face of scarcity and abundance based on environmental contingencies, then those cues will serve to trigger specific risk-taking behaviors in other arenas, including political contexts. This will be especially likely if the survival of early humans depended on political decisions about cooperation and resource distribution among group members (Boehm 1999).

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[3]This is true as long as the means are finite, the variances are positive and finite, and $\sigma^2_{risky} \neq \sigma^2_{safe}$

For example, political leaders who make decisions with regard to international challenges may accept greater costs to regain the previous reference point in the face of losses—having living soldiers die to justify past losses provides only the most salient example of this type of strategy. We often see leaders taking much greater risks in the area of war, involving life and death, than we do in international economic relations, which largely involve money, trade, and wealth (Fagley and Miller, 1997; Kuhberger, Schulte-Mecklenbeck, and Perner 1999; McDermott 1998). Indeed, we would expect such differences in risk propensity based on our model. Leaders who espouse a constant risk strategy may do well in certain environments, as our earlier bold and meek individuals succeed in scarce and abundant environments, respectively. But leaders who demonstrate flexibility and the ability to switch strategies based on particular environmental contingencies may do best of all, especially in environments where threats to survival change over time.

The behavior of ordinary citizens is also likely to be influenced by prospect theory preferences. Just as a willingness to take risk varies with the current hedonic state of the individual in our model, the current state of an individual may influence their perspective on a wide variety of political issues, from immigration to war. The reference point of given individuals may differ based on their level of wealth, for example, but the basic risk propensity of preferring caution in good times, and risk in bad, is likely to remain robust in general if it is underscored by the evolutionary processes we suggest. Risk acceptance proclivities in the domain of losses may explain, for example, why voters appear particularly willing to take large risks and chances when things are going badly (Weyland 1996).

Prospect theory also has implications for coalitional behavior. The size and strength of alliances may prove central in individuals' assessments of the challenges they confront, and their ability to respond successfully to them. Just as animals face a trade off in deciding whether to forage for food alone or in groups (Houston, McNamara, and Hutchinson 1993), leaders, members of Congress, and individual voters face a similar calculus in decisions about who to support politically and how much to sacrifice on behalf of their communal concerns. In the animal world, foraging with others increases the likelihood of finding food and also reduces the risk of predation. But such a strategy also potentially reduces the amount of food an individual can eat if he must share with his foraging partners. Similarly, individual

voters and leaders face complex coalitional choices in most political decisions.

Allocating time and energy to such decision making constitutes an important adaptive task, which requires a great deal of mental accounting as well. Delegating particular communal concerns to established representatives can provide an important mechanism for confronting risk within the context of a particular preestablished coalition, such as a political party, ethnic group, or religion. The problem of course is that such behavior evolved in the context of much smaller groups than modern political organizations, and these strategies may no longer be adaptive within our much larger current social and political environment. But the tendency to expect cooperation and service from leaders remains. Just as tribal societies value cooperation and egalitarianism, and punish aggression and self-aggrandizement in leaders (Boehm 1999), modern societies seek to punish ethical violations on the part of our leaders through sanctions including job loss, jail, and in certain societies, death. Similarly, triggers and adaptive programs evolved for one context become entrained to respond to established cues embedded within entirely different substantive areas in predictable ways. For example, voters might worry that a politician who cheats on his wife may similarly cheat on his coalition, acting as a free rider, or taking undue rewards, while others may feel the need to support one's own national alliance and coalition under conditions of conflict, in fear of being overwhelmed by the enemy.

Revisiting Extant Political Models

If existing theoretical and empirical models and our alternative *prospector* model generate the same results, then our theory would not be of much importance. However, we note that most models of politics typically have ***not*** assumed prospector preferences, and this has caused them to generate important results that cause scholars to make incorrect inferences in at least some cases. It is not true that extant models are always wrong, but rather that they are reliably right under certain conditions, and that they are predictably, systematically incorrect regarding other conditions, specifically those involving risk or threat to survival. It may be that standard models work well when environmental conditions are characterized by abundance. However, when the external situation changes and individuals or groups begin to face real or perceived threats to survival, preferences will change in the predictable way that we have demonstrated, and this will have an effect on

inferences drawn from important models in each major subfield of political science. Certainly alternative explanations exist for all these models, but we present some illustrations of how an evolutionary lens can shift our understanding.

American Spatial Voting Models

Black (1958) and Downs (1957) conceptualized a broad set of political decisions as being *spatial* in nature. Policies are located in an ideological space, and each individual has a certain ideal policy in mind when they compare alternatives. The utility of a given alternative is inversely related to the Euclidean distance between it and the individual's ideal policy. Later scholars developed the spatial theory (e.g., Davis, Hinich, and Ordeshook 1970) and used it to generate sophisticated models of party competition (e.g., Roemer 2001; Wittman 1977) and the legislative process (e.g., Baron and Ferejohn 1989). These models have greatly improved our understanding of politics, but the vast majority of them have made strong assumptions about risk in order to achieve tractability. For example, the canonical risk assumption in this literature is quadratic utility—alternatives become worse with the square of the distance from one's ideal point (Austen-Smith and Banks 1988; Baron 1994; Martin 2001). Quadratic utility functions are mathematically convenient for finding equilibria since they differentiate to linear functions, making optimization easy. A related but more general risk assumption is that the utility function is concave in the distance from the ideal point (Banks and Duggan 2000; Huber and McCarty 2001; Weingast 1989). This form is convenient because the sum of two concave functions must also be concave, meaning proofs of equilibrium existence can be supported by several theorems related to concavity (like the single-crossing property).

However, these gains in tractability come at a price. Prospect and optimal foraging theories suggest that spatial utility is neither quadratic nor concave. Individuals concerned with survival are likely to be risk averse when the alternatives are close enough to the ideal to guarantee staying alive. However, if the alternatives are farther away, survival may depend on accepting a risky alternative. At a certain extreme, alternatives may be so distant that none yield a significant improvement in survival, even if the alternatives themselves are quite distant from one another. In other words, at a certain point individuals will be indifferent between a very distant alternative and a very, very distant alternative. In prospect theory

models, the weighting function represents this dynamic well; the end-points (outcomes judged to be either certain or impossible) are not well behaved precisely because psychological assessment remains indifferent between such choices.[4] This reasoning suggests that the utility of a policy will be *s*-shaped—concave near the ideal point and convex at the extremes, flattening out as the distance tends to infinity. The largest differences in utility will occur between equally spaced alternatives that are only moderately distant from the preferred alternative.

Psychological evidence suggests that human decisions do conform to an *s*-shaped spatial utility function. For example, Shepard (1962) shows that people are better able to discriminate hues close to their favorite hue. A wide variety of other discrimination tasks suggest that a basic property of human perception is the ability to scrutinize differences in preferred objects and the inability to detect similarly sized differences in less-preferred objects (Shepard 1987). This is similar to findings in psychology concerning ingroup effects, whereby people see more variation within members of their social ingroup than among outgroup members, who are perceived as largely homogenous (Ostrom and Sedikides, 1992). Moreover, psychologists like Nosofsky (1986) have explicitly linked discrimination ability to the framing effects observed by Tversky (1977)—they argue that the frame serves to focus attention on similar outcomes, which makes it harder to determine differences in less similar outcomes. For these reasons, Poole (2005) argues that spatial utility functions should be *Gaussian* instead of quadratic because they are more consistent with evidence from the psychological literature on discriminant ability.

The convexity at the extreme of the spatial utility function invalidates the proofs of several important spatial models, most notably models of party competition (Downs 1957; Roemer 2001; Wittman 1977). In particular, Roemer (2001) compares standard models and notes that the assumption that parties care only about winning office generates an unrealistic equilibrium—namely, both parties in a two-party system will offer exactly the same policy to the voters. As a consequence, he infers that parties must also care about policy since models that make this assumption are able to generate equilibria in which the two parties offer different policies. However,

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[4]Tversky and Kahneman (1992) developed a version of prospect theory, called cumulative prospect theory, that allowed endpoints to converge. This theoretical model does not affect the experimental findings which demonstrate clear deviation around the endpoints.

suppose voters have Gaussian instead of quadratic utility functions. If so, then some extremists may be *alienated* and may choose to abstain instead of voting for the closest moderate party—in essence, they stay home because "there's not a dime's worth of difference" between the two parties (Adams, Dow, and Merrill 2006). Knowing this, the parties have an incentive to shift their policies towards their "base"— even if they are purely office seeking (Adams and Merrill 2003).

In another theory of party competition, Alesina and Rosenthal (1995) develop an elaborate "electoral balancing" explanation for why the President's party tends to lose seats in midterm elections. This explanation relies on sophisticated coordination strategies among moderate risk-neutral voters who split their ticket and then switch their vote at the midterm if their preferred candidate for President loses. In contrast, Patty (2006) shows that the simple assumption of prospect theory preferences implies that abstaining supporters of the losing party in the Presidential election will have a greater incentive than those who won to cover their loss by showing up to vote in the midterm election.

Thus, prospect theory helps to simplify key problems in American politics by generating results that are consistent with party behavior (policy divergence) and voter behavior (abstention due to alienation, voting against the President's party) that flow directly from a widely tested and plausible assumption about risk. We acknowledge that there are many alternative hypotheses that explain alienation, divergence, and midterm loss, but if these theories are based on quadratic or quasi-concave spatial utility functions then they, too, are suspect. It may make sense to assume such preferences when we expect the issue domain to be narrow around ideal points or to have little effect on the survival of groups or individuals, but not for big issue spaces with broad implications. Thus, models that assume strict risk aversion or neutrality may miss out on the opportunity to answer questions about the most important problems in American Politics.

Conflict Models in International Relations

Some important models in international relations take account of prospect theoretic type preferences (Jervis, 2004). However, in many analytic models of international security, the nation-states (or their leaders) are assumed to be risk averse or risk neutral, and this assumption drives some important results.

For example, in one well-known article, Fearon considers two nation-states that must decide between engaging in a costly war and arriving at a negotiated settlement. He shows that there always exists a negotiated settlement that both sides will prefer, as long as the range of possible settlements is continuous, the two nation-states share a common belief about the probability of who will win the war, and they are both risk averse (or risk neutral). As a result, he argues against "the conventional view that rational states can and often do face a situation of deadlock, in which war occurs because no mutually preferable bargain exists" (1995, 409). What Fearon does not consider is the relationship between the territory or power under dispute and a nation's or a leader's survival. When the negotiated settlement puts survival at risk, a war—even one with a lower expected value than the negotiated settlement—may be preferable.

> Fearon explains his choice to assume risk aversion: "In effect, the assumption means that leaders do not like gambling when the downside risk is losing at war, which seems plausible given the presumption that state leaders normally wish to retain territory and power. A risk-acceptant leader is analogous to a compulsive gambler—willing to accept a sequence of gambles that has the expected outcome of eliminating the state and regime. Even if we admitted such a leader as rational, it seems doubtful that many have held such preferences (Hitler being a possible exception)." (388)

However, prospect theory and the model presented in this article suggest that we should expect the same decision makers to be risk averse when survival is assured and risk acceptant when it is not, helping to explain the Hitler exception along with many important others (Stalin, Mao, etc.). Therefore, a proper model of international conflict should be based not only on the individual *characteristics* of the decision maker (s), but also on the *context* of the conflict. Indeed, one of the insights provided by prospect theory highlights the central influence of the situation on the risk propensity of any given leader. The interpretation and perception of that environment may differ across individual leaders (i.e., the point at which he understands his survival to be at risk), but the importance of such variables on choice remains critical and constant. Many international conflicts— in fact, our most important ones—have threatened survival, placing decisions in the domain of losses and giving leaders and peasants alike an incentive to gamble to stay alive, remain in power, or to keep their nations safe (Downs and Rocke 1995; Popkin 1979). Under this assumption, Fearon's model generates a conclusion opposite to the one he drew: some conflicts are actually intractable.

The positive and normative implications of prospect theory preferences for international relations are tremendous. Although scholars like Fearon make substantive claims about the assumption of risk aversion, one of the main reasons analytic modelers assume it is for the sake of mathematical convenience. Risk aversion implies concavity in utility functions, and a number of general results about concavity help to ensure the existence of a unique equilibrium. However, this is a costly assumption to make if it affects inferences. Prospect theory and optimal foraging theory suggest that we should not treat the conflict between Israel and Palestine as though it were equivalent to the soft lumber dispute between Canada and the United States. If parties to the Arab-Israeli conflict see their survival at stake, then a mutually acceptable alternative to war may not exist.

Our perspective remains quite consistent, however, with sophisticated rational choice arguments comparing regime type and political accountability in explaining the survival of political leaders in office (Bueno de Mesquita and Siverson, 1995). Bueno de Mesquita et al. (1999, 2002, 2005) seek to account for these observed differences in political survival and war by examining the basis and nature of resource allocation. A democratic leader must rely on large winning coalition to remain in power while an authoritarian leader depends on a much smaller "selectorate" to retain political viability. Most leaders are reluctant to accept a sure loss to their own political power and thus are willing to take risky actions such as war to avoid such a loss. This view provides an empirical demonstration of the risk-sensitive nature of political decision making; when political or physical survival is threatened, leaders appear much more likely to engage in risky actions like war.

Models of Economic Development and Reform in Comparative Politics

An important topic that has recently captured the attention of many scholars in comparative politics is the decision by some leaders to implement radical economic reform, particularly in areas struggling with economic development and democratization. From Latin America to Eastern Europe, leaders like Alberto Fujimori in Peru institute bold economic reforms with severe costs for the population and, surprisingly, receive widespread support for such action. Similarly, leaders such as Boris Yeltsin in Russia and Vaclav Klaus in the Czech Republic were reelected despite instituting costly economic adjustment plans.

Many extant theories have difficulty accounting for risky actions such as these on the part of leaders, much less explaining widespread support for such action. For example, some rational choice models assume widespread risk aversion, suggesting that leaders will eschew radical reform because they fear such policies will lead to their eminent electoral failure (Ames, 1987; Geddes, 1995; Remmer, 1991). Similarly, rational choice theorists argue that popular groups or leaders will capitulate immediately to the pressures of popular opposition and stop or refuse reform in order to avoid the political costs inevitably associated with further economic decline (Alesina and Prelec 1991).

Such arguments extend beyond the area of neoliberal economic reform into the realm of explaining public support for economic stabilization as well. Rodrik (1994), for example, argues that voters will eventually prefer the benefits of preventing or ameliorating a severe economic crisis over the distributional costs which triggered previous opposition to structural economic reform. Similarly, Przeworski (1991) must implicitly assume risk acceptant policy makers and publics in his rational choice explanation for the pace of economic readjustment and stabilization. Although the uncertain nature of such reforms suggests that the structure of economic incentives drives politicians to enact radical economic reforms quickly, it still leaves such politicians vulnerable to public and electoral protest. Note that the implicit risk acceptance in this model diverges from the implicit risk aversion assumed by other rational choice models in this debate (Geddes 1995).

More recent arguments focus on switching strategies employed by Latin American politicians (Stokes 2001) which are consistent with the prospecting model we present here. In discussing how politicians invoke a switching strategy between efficacy-oriented or welfare oriented policies, Stokes argues that unpopular policies are often best for the welfare of constituents, and thus for the long-term political interests of their representatives.

Indeed, such prospect-oriented risk propensities have been demonstrated among many states and political leaders in Latin American and Eastern Europe (Weyland 1996, 1998). For instance, Weyland (1996) demonstrates how leaders facing economic crisis in Argentina, Brazil, and Peru enacted bold, risky, and costly strategies which elicited strong popular support. By contrast, leaders in Chile pursued more cautious policies while facing better economic prospects. In later work, Weyland (1998) employed prospect theory to examine the stages of economic reform and stabilization in a large number of countries within

Latin America, Africa, and Eastern Europe. His arguments demonstrate that prospect preferences can explain both why politicians may enact costly reform policies and why they receive high levels of popular support for these strategies when people exist at near-subsistence levels. This model also explains why such policies do not find as much support in relatively more stable economies such as Chile. It also provides a coherent explanation for why leaders and publics may shift from avoiding the risk of economic stabilization policies to accepting this risk. Thus, prospect preferences provide a more comprehensive and parsimonious model than the extant rational choice models to explain this wide variety of approaches to reform across many regions of the world.

Conclusion

Adapting a model from optimal foraging theory, we have demonstrated how risk seeking in losses and risk aversion in gains can represent an optimal strategy for a person evolved to maximize his prospects for survival in environments that vary between abundance and scarcity over time. These strategies represent an important element of human cognitive hardware for solving adaptive problems related to risk taking under uncertainty. We suggest this kind of risk propensity operates as an evolutionary module in human psychological architecture. Environmental contingencies cue particular responses in automatic ways; abundance leads to caution, while scarcity provokes risk. Further evidence in support of this innate bias comes from primates who demonstrate similar tendencies in experimental contexts (Chen, Lakshminarayanan, and Santos 2006; Brosnan et al. 2007).

Our model demonstrates ecological rationality, or how prospectors can do better over the long term, thus providing an evolutionary fitness advantage that would be passed along to descendants. If *bold* individuals always make the risky choice, they will do better in environments of scarcity; if *meek* individuals always take the safe option, they will do better when times are abundant. If the best survival strategy changes depending on shifting environmental contingencies, then *prospectors* are most likely to prevail under conditions of uncertainty, as we see in the classic prospect theory curve. Uncertain environments naturally select for individuals who prefer high-variance payoffs, even when such outcomes offer lower expected value. Such individuals take risks when their survival is threatened, and otherwise they play it safe.

In other words, the *prospector* will make a risky choice only when such an option offers a higher probability of survival. As the environment becomes more certain or more abundant, *prospectors* become more cautious. Importantly, the relative survival benefit for *prospectors* depends on environmental uncertainty; further, one would expect such prospect theory tendencies in risk propensity to manifest most strongly in the arena of life and death decisions.

This evolutionary model, while specifically designed to provide an explanation for the origins of prospect-type preferences, may also possibly serve to inform the origin of preferences from within more normative models such as subjective expected utility theory. While most rational choice theorists remain uninterested in explaining the origins of preferences, accepting them as exogenous, evolutionary models provide helpful cues for the development of particular tastes. For example, humans evolved to prefer meat and high sugar, high-fat tastes because of their caloric value. Individuals who partook of such foods clearly avoided starvation at a higher rate than those who did not. But such foods were rare in the environment in which humans evolved; meat was scarce and largely lean, while most sugar came from fruit and honey and most fat derived from nuts. Having such food preferences in the current context of fattened beef and processed sugars and fats often leads to bad health outcomes. Similarly, political strategies which proved effective in small hunter-gatherer bands may not prove as adaptive today within the context of larger social groups with more diverse interests and goals.

To be clear, we are not arguing only that understanding the sources of preferences can be interesting in its own right, although we believe that to be the case. Rather, we are emphasizing the fact that such an evolutionary origin for prospect theory type preferences, particularly contingent on perceptions and contingencies surrounding survival, holds significant implications for human decision making and behavior. Prospect theory represents more than a bag of cognitive biases without rhyme or reason; in our view, it represents a comprehensive module of human preference concerning risk. Such a module, with roots deep in human evolutionary history, aided chances for survival, and would prove highly resistant to change or learning through experience or education over time. It would not be easily corrected by policymakers, but, when harnessed properly, could quickly and efficiently be manipulated by sophisticated leaders to encourage those whose survival felt threatened to support risky policies. In this way, we argue that the evolutionary origins of prospect theory preferences

hold profound implications for decision-making analysis.

Prospect theory was developed through a series of elegant empirical demonstrations conducted by Daniel Kahneman and Amos Tversky. Prospect theory behaviors have been typically presented through the prism of bounded rationality—in fact, equated with irrationality (Kahneman and Tversky 1982). Human cognitive modules, however, have been designed not for economic rationality in a consumer environment of abundance, but for "hot cognition" to respond to "crucial events related to survival and reproduction" (Kenrick, Sadalla, and Keefe 1998, 488). In this respect, psychological biases helping individual survival are "better than rational" (Cosmides and Tooby 1994). As evolutionary psychologists further point out: "If humans had evolved in casinos where their winnings translated into reproductive success, selection probably would have eliminated the gambler's fallacy. But in the real world it often pays to behave as if the past and future are not independent" (Gaulin and McBurney 2001, 175). In the real world it pays to be adaptively rational; and if evolutionary advantage gives you advice different from the one suggested by logic—then you will be "worse for the logic" (Fox 1992). Human heuristics, therefore, enable us "to make reasonable decisions and behave adaptively in our environment—Homo sapiens would be lost without them" (Gigerenzer 1999, 29).

The authors of prospect theory and most of their followers did not need or provide an evolutionary perspective to explain or justify their findings. However, such a link provides a comprehensive and consistent explanation for the evolution of such risk-taking propensities, pointing to their innate basis. Optimal foraging theory explains why evolved sensitivity to probability and variance, within the context of particular needs and environmental contingencies, proves a quite ecologically rational strategy. If our analysis for the origins of such preferences is correct, eliminating such biases in judgment and decision making will prove even more challenging, and unlikely, than previously assumed.

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