Perception Matters:
Psychophysics for Economists

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I. Introduction

Experimental economics, behavioral game theory, and behavioral decision research have made great strides in recent years towards their goal of predicting behavior, especially in those cases where it deviates from the predictions of conventional economic rationality. Many, if not most of these advances fall into two categories, both of which assign a causal role to decision makers' perception, that is, their construal of the decision situation. [i] Category I explanations acknowledge the *constructive* and hence *subjective* nature of perception. Category II explanations emphasize the *relative* nature of perception. Section I of this paper describes these two categories of explanations and the way in which they modify standard theory. Section II provides an introduction to the field of psychophysics, an interdisciplinary area of investigation that started psychology as a scientific discipline in the second half of the 19th century. In psychophysics, the theoretical and empirical investigation of the constructive, subjective and relative nature of perception and its relation to judgment and choice have had a long history. Broader knowledge of this research tradition and its insights about the modeling of human choice behavior may be helpful for economists and prevent unnecessary duplication of effort, allowing economics to build on (rather than reinvent) psychology. Section III describes some recent insights that psychophysical insights have brought to the modeling of risky choice and provides suggestions for the direction that cumulative theory building across disciplines might take.

Category I Explanations: Perception is Constructive and Subjective

People's subjective construal of their situation is a major theme in many non-standard economic accounts of judgment and choice (see Loewenstein, 2001). For such phenomena as framing (Tversky & Kahneman, 1981) or prominence (Tversky, Sattath, & Slovic, 1988), small differences in characteristics of the decision or judgment tasks influence the way in which the decision maker perceives the value or importance of choice-relevant information (Payne, Bettman, & Johnson, 1993), making their interpretation subjective and constructive. Explanations that draw on the role of surface content in decisions (Goldstein & Weber, 1995) and games (Larrick & Blount, 1997) also fall under this category. These explanations posit that surface content (i.e., what the game or decision is ostensibly "about") influences the mental representation and subsequent use of structurally equivalent information (Rettinger & Hastie, 2001).

Category II Explanations: Perception is Relative

Conceptual innovations of this type are an important subcategory of Category I. While implicitly acknowledging the *subjective* nature of perception, Category II explanations specifically emphasize its *relative* nature. Many researchers have documented differences in the ease, accuracy, and reliability with which people provide absolute vs. relative evaluations. In particular, people find it easier to make relative comparisons rather than provide absolute judgments and often convert tasks that may (ostensibly and normatively) require absolute judgments into tasks that can be solved by relative judgments. When the writer James Thurber, shortly after his marriage, was asked by a reporter how he liked his new wife, he apocryphally replied with the question: "Compared to what?"

A thought experiment illustrates the relative nature of perception on a dimension as basic as water temperature. Imagine three buckets of water on a table in front of you. The left bucket contains very hot water. Put your left hand into that bucket. The right bucket contains ice water. Put your right hand into that bucket. Leave both hands in their respective bucket for a minute. Now place both hands into the middle bucket, which contains water at room temperature. You will be hard pressed to believe your eyes, which tell you that both hands are in the same bucket. Nevertheless, your left hand will experience the room temperature as very cold, while your right hand experiences it as very hot. Each hand's sensation is driven by a comparison and contrast to the temperature that preceded immersion in the middle bucket.

What holds for simple sensory judgments also appears to hold for high-level judgments such as utility. While it is not easy to ascertain how happy to be about a salary increase of $300, it is very easy to be unhappy about an increase that is only half that of a colleague. Social comparisons have been shown to play a prominent role in a wide range of situations (Loewenstein, Thompson, & Bazerman, 1989). Similarly, a win of $1,000 in a lottery may be of uncertain utility, but a win that is only a small percentage of what one could have won, had one chosen another lottery, clearly is a disappointment (Loomes & Sugden, 1986). Hsee (1996) showed that people's evaluations of the utility of a wide variety of outcomes often require relative comparisons, especially in the absence of expertise with the choice domain.

Decisions that require absolute judgments often show inconsistency across time or context. Thus, obviously irrelevant numeric anchors have been shown to affect the absolute level of willingness-to-accept prices to give up desirable objects or activities (Chapman & Johnson, 1999), even after the disciplining impact of market feedback (Ariely, Prelec, Loewenstein, 2001). Relative judgments, however, show consistency and monotonicity in such situations (Ariely et al., 2001).

II. Psychophysics: Mapping Objective Reality into Subjective Perception

Psychophysics is the scientific discipline that studies how the stimulus energy of objective events (the *physics* part of psychophysics, e.g., the electromagnetic energy of a beam of light) gets translated into subjective sensation and perception (the *psycho* part of psychophysics, e.g., perceived color and intensity). In psychophysics, the theoretical and empirical investigation of the constructive, subjective, and relative nature of perception and its relationship to behavior has had a long and illustrious history. Classic psychophysical regularities (e.g., the Weber-Fechner law described below) have had impact on theory development in many disciplines outside of psychology, including behavioral ecology and decision research.

In addition to demonstrating the crucial role of subjective perception as an intervening construct between objective events and people's responses to them, psychophysical research has illustrated a principle with important methodological implications for behavioral economics. Briefly put, the principle is that "*process matters.*" Process matters in two ways that go against the economic tradition of modeling only the outcomes of decisions. First, cognitive processes executed in the service of a judgment or decision often have observable correlates (e.g., information acquisitions, including eye movement fixations), which can serve to test between competing explanations for an observed pattern of choices, if those explanations make different assumptions about cognitive processes but identical predictions for final decisions (see Johnson & Camerer, this volume). Process tracing studies of behavior in games (Costa-Gomez, Crawford, & Bruseta, 2001; Johnson, Camerer, Sen, & Rymon, 2002), for example, demonstrate that information about the sequence of information acquisition helps to tests between explanations for observed results that differ in strategic sophistication. With the recent advent of neural imaging technology, economists have shown increasing interest in the ability of process measures such as blood flow to different brain regions (indicative of activation) or reaction time to provide evidence for differences in choice processes even in the absence of observed differences choice outcomes (Dickhaut et al., 2003; Smith et al., 2002)

Secondly, *process matters* in the sense that people seem to have access to information about the time course, difficulty, and other aspects of their subjective experience while providing a judgment or reaching a decision, and often use such information for their decision or for meta-cognitive judgments about the decision. Research on risky decision making, for example, has shown that feelings of dread experienced during a decision influence risky choice to an extent that can be equal to or greater than the effect of statistical information about possible outcomes and their likelihood (Holtgrave & Weber, 1996; Loewenstein, Weber, Hsee, & Welch, 2001). Work on decision modes (Weber, 1998; Ames, Flynn, & Weber, 2001) demonstrates that people pay close attention to the processes by which they and others arrive at decisions, and that such information may influence choice, but also perceptions of the decision makers that have consequences for future decisions. Confidence judgments for psychophysical judgments, described below, provide another illustration that "process matters." The interpretation of confidence judgments in psychophysics may provide some explanation of confidence judgments and overconfidence in other contexts.

Psychophysics: Perception is Constructed

Hermann von Helmholtz, a physicist and physiologist, pioneered the experimental study of vision. Contrary to the idea that perception is simply a matter of "copying" sensory input into the brain, Helmholtz (1866) demonstrated that even the most basic aspects of perception require major acts of construction by the nervous system. Take the example of two objects--a large one far away, and a small one near by--that create precisely the same image on the retinas of a viewer's eyes. Yet, most viewers will correctly perceive the one object as being larger, but further away than the other. The brain manages this by performing geometrical calculations that incorporate implicit knowledge of spatial regularities and constraints. It constructs the correct representation by a process of unconscious inference. Helmholtz' insight was that the "objective" reality we perceive is not simply a copy of the external world, but rather the product of the constructive activities of the brain.

Another example of the constructive nature of perception is provided by the apparent visual constancy of the perceived world during body and head movements on part of the viewer. Even though the world's and the body's frames of reference change orientation with respect to one another, the brain knows to attribute this change to motion of the organism rather than to motion of the world and thus perceives the world as constant. Scientists such as Mach (1885) and Sherrington (1918) concerned themselves with aspects of the visual constancy problem, which continue to attract attention (e.g., Bridgeman, Van der Hejiden, & Velichkovsky, 1994).

A final illustration of the constructed nature of perception is our lack of awareness of saccadic suppression. Saccades are frequent, periodic eye movements that occur to gather visual information or to prevent habituation (as discussed in the next section). The movement is ballistic, and during its execution the brain blocks out visual information. Rather than perceiving reality as a series of snapshots interrupted by dark periods, however, the brain constructs a seamless representation of visual reality (Matin, 1974).

Psychophysics: Perception is Relative

In the process of specifying the functional mapping between objective stimuli and subjective experience, psychophysical research has demonstrated that the sensory system of humans (and other animals) predisposes us to be sensitive to *changes* in sensory stimulation, rather than to absolute levels. One of the most characteristic properties of sensory receptors is that they adapt to maintained stimulation. Receptors may differ in the speed by which they adapt and may use different neurophysiological mechanisms to do so, but the phenomenon of adaptation is virtually universal (Kandel, Schwartz, & Jessel, 1995). A constant level of stimulation results in a gradual decline in perceived intensity. Personal experience with sensory adaptation abounds. The onset of a sound (e.g., the high-pitched whistle of a defective fan) may initially give rise to an aversive and possibly even painful sensation. However, as time passes our sensory system adapts, and we may eventually even cease to hear the sound. In the case of vision, our sensory system has dealt with adaptation by making sure that our eyes will not perceive the same impression for long (Steinman and Collewijn 1980). Body, head, and eye movements change the position of the eyes relative to the world almost constantly. Even during steady fixation with the head immobilized, a variety of small eye movements (micro-saccades) constantly change the position of the eyes relative to the world. Such eye movements require the constructive capacity of our brain to do its job as discussed in the previous section, to give us the useful impression of a stable world.

For organisms with limited attentional capacity, it is undoubtedly adaptive to allocate capacity to the detection of *changes* in the environment. Detection of a given level of stimulation has decreasing utility as time goes by, given that time is of the essence for reactions to most new events, e.g., the appearance of a predator, a change in water temperature that might scald the person taking a shower, or a change in the value of an investment opportunity.

The anatomist Ernst Heinrich Weber and the physicist and philosopher Gustav Fechner studied the relation between changes in the objective magnitude in physical stimuli (such as brightness or weight) and the subjective magnitude of internal sensation these stimulus changes generate. Their psychophysical investigations of people's judgments of stimuli on simple sensory continua (e.g., loudness, brightness) showed that changes in objective magnitude did not map onto differences in subjective magnitude in a simple fashion. Rather, the magnitude of change in intensity required to perceive a new stimulus as different from a previously presented (old) stimulus, ΔI:

$$\Delta I = I_{new} - I_{old} \qquad \text{(Equation 1)}$$

was found to be proportional to the initial stimulus intensity I_{old} (Weber, 1834):

$$\Delta I / I_{old} = k \qquad \text{(Equation 2)},$$

where k is a constant whose value depends on the specific stimulus dimension.

ΔI is often referred to as the "just noticeable difference" (or JND) and provides a measure of discriminability in psychophysical judgments. Equation 2, known as Weber’s law, implies that discriminability is finer at low levels of stimulus magnitude and decreases at larger levels. Variability in stimulus intensity is not perceived in an absolute way, but relative to the average level of stimulation, a phenomenon that will be shown to explain regularities in people’s reactions to risk that violate standard economic theory.

Process Matters: Confidence as Experienced Decision Conflict

Early psychophysical research demonstrates that people reliably use information about the processes by which they make judgments or decisions, even if such information is preverbal and thus not fully conscious. Confidence judgments provide a good example. Since the ascendancy of information theory and Bayesian statistics in the 1950s, confidence in a judgment or decision has been thought to reflect the decision maker's subjective assessment that their judgment or choice is correct (Oskamp, 1965). Confidence in a hypothesis, for example, is assumed to reflect the scientist's belief that the hypothesis is correct, given the available data or evidence. Within a Bayesian framework, people may assess this probability using different indicators that include their knowledge about the predictive validity of available cue information (Gigerenzer, Hoffrage, & Kleinboelting, 1991), knowledge of the base rate with which the answer is correct (Bar-Hillel, 1980), or the amount of evidence supporting the answer (Koriat, Lichtenstein, & Fischhoff, 1980). Some of these indicators may be fallible and thus result in inaccurate estimates of likely accuracy. Nevertheless, all of these accounts assume that people intend to express the likely accuracy of their choice or judgment with their confidence judgment.

Early psychophysical research, on the other hand, discovered that confidence judgments were not so much *forward*-looking (in the sense of trying to predict the likely accuracy of a provided answer), but instead were *backward*- and *inward*-looking, in the sense of describing some aspects of the decision maker's subjective (and not necessarily verbalizable) experience during the process of coming up with the answer. Looking for a measure of uncertainty in discrimination judgments, the American psychophysicists Peirce and Jastrow (1884) discovered a simple functional relationship between average confidence judgments and the proportions of correct responses in psychophysical discrimination tasks across a variety of conditions. Ceteris paribus, the proportion of correct over incorrect responses (measured by the experimenter over trials) and confidence in the discriminations (expressed by the decision maker on each trial) were found to be equivalent and substitutable expressions of an individual's ability to discriminate between a certain set of stimuli. For example, as the physical difference in intensity between two test stimuli increased, the proportion of correct "different" and "same" judgments went up, as did average confidence in the discrimination judgments.

Confidence judgments had the advantage of being easier to obtain than response proportions, providing reliable estimates of the relative difficulty of judgments after a smaller number of trials. While clearly related to accuracy most of the time, confidence judgments seemed to express some aspect of the subjective experience of the discrimination process, providing information about the difficulty experienced in arriving at the final decision. Henmon (1911), for example, showed that when accuracy was held constant, judgments that had a slower response time were made with less confidence.

The interpretation that confidence judgments reflect the experience of process-level conflict (e.g., conflict between one's belief in different answers or between one's preferences for different alternatives) in ways that go beyond the predictions of a Bayesian belief updating model is consistent with other recent research results. Zakay (1985) found that in decisions made by nurses, ratings of post-decision confidence were significantly higher when the nurses had been instructed to use non-compensatory choice processes (that entailed less decision conflict) than when choices were made using a compensatory strategy (that necessitated conflictive tradeoffs). A purely information-theoretical interpretation of decision confidence would predict the opposite results or, at best, no difference in confidence. Along similar lines, Weber, Böckenholt, Hilton, and Wallace (2000) were able to explain gender differences in the confidence judgments made by physicians about their diagnostic decisions by differences in the cognitive complexity of the task representation and the resulting process-level conflict engendered by the decision. Doctors who entertained competing diagnostic hypotheses (rather than just a single one) and thus provided a differential diagnosis, were less confident in their decision, controlling for the accuracy of their decisions. Since female doctors were more likely to have complex task representations that engendered decision conflict, they tended to have lower confidence in their diagnoses than male doctors. However, the relationship between quality of decision process and confidence judgments held for both genders. These results may shed light on gender differences in confidence and overconfidence in other contexts, including those that have recently been suggested as explanation for gender differences in the frequency of stock trading (Barber & Odean, 2001).

In summary, confidence judgments seem to reflect something about the introspective quality of the processes that give rise to a judgment or decision. The nature of the available information, existing representations, as well as context and task features all affect the quality of decision processes, either facilitating or complicating the course by which an answer is reached. Judgments of confidence are inward-looking in the sense that they express something about the experience of arriving at a final judgment or decision and thus serve as a type of "memory" of the processes that gave rise to it. While they are often related to accuracy, as in the original psychophysical experiments, they probably do not have the expression of accuracy as their primary goal.

III. Psychophysics and Economic Risky-Choice Models

Psychology as a discipline has had its most noticeable influence on economics in the area of human decision making, in particular decision making under risk and uncertainty. Prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992), as a notable example rewarded by the 2002 Nobel Prize, describes and formalizes the ways in which observed choice behavior deviates from the predictions of expected utility theory. Subsequent work (e.g., Weber & Kirsner, 1997; Diecidue & Wakker, 2001) has provided psychological explanations for such phenomena as the rank-dependent weighting of utility in terms as a response to cognitive or motivational goals or constraints.

An alternative to the expected utility and prospect theory framework of risky choice is provided by the risk—return framework employed in finance (Markovitz, 1959). In this framework, preference is seen as a compromise between greed (return) and fear (risk). Risk—return models in finance equate "return" with the expected value of a risky option and "risk" with its variance. Generalized risk—return models allow for a broader range of risk measures (Sarin & M. Weber, 1993; Jia & Dyer, 1996). In this section, I will review the growing body of evidence that perceptions of risk—just like psychophysical perceptions of intensity or brightness—are subjective (i.e., differ across situations, individuals, cultures, and genders) and relative (i.e., depend on a standard of reference). These results have implications for the interpretation of observed differences in risk-taking, allowing for a richer set of possible explanations (see Weber & Milliman, 1997; Weber, 2001a). In particular, individual or group differences in risk-taking may be the result of differences in the perception of the riskiness of the choice options, rather than being solely attributable to differences in risk attitude. Cooper, Woo, and Dunkelberger (1988) report, for example, that—contrary to managerial folklore—entrepreneurs differ from other managers not by a more positive *attitude* towards risk, but instead by an overly optimistic *perception* of the risks involved. For an outside observer who perceives risks more realistically, entrepreneurs will thus appear to take great risks. After differences in risk perception are factored out, entrepreneurs—just as other managers—demonstrate a preference for tasks that they see as only moderate in risk (Brockhaus, 1982).

Risk Perception is Subjective

Economics is virtually alone among the social sciences in the assumption that risk is a stable, objective, inherent characteristic of risky choice options that will be perceived identically (or at least similarly) by different individuals. The pioneering work of Douglas and Wildavsky (1982) in anthropology hypothesized that risk perception is a collective phenomenon, by which members of a given culture attend to risks that threaten their interests and way of life (see Weber, 2001b for a summary). Palmer (1996) found some evidence for this socio-cultural theory of risk perception in the form of systematic differences in the judgments of financial and health/safety risks posed by a set of activities among respondents who came from subcultures with different worldviews (hierarchical, individualist, egalitarian) in Southern California. Management science, assumes that aspiration levels will affect the risk perceptions and thus choices of both individual managers (March & Shapira, 1987) and firms (Cyert & March, 1963).

There is a large literature on subjective risk perception that allows us to model and predict individual and group differences in perceived risk (for recent reviews see Brachinger and M. Weber, 1997; Bontempo, Bottom, and Weber, 1997; Holtgrave and Weber, 1993; Weber, 1997; Yates and Stone, 1992). This literature shows that, while individual differences in risk perception exist, group differences are even larger and sufficiently systematic to result in predictable group differences in risk perception as a function of gender, income, and cultural origin.

Risk Perception is Relative

Savage (1954, p. 103) described a regularity in people's subjective evaluation of outcome differences or variability closely related to Weber's law in the context of riskless choice. Differences in outcome values are judged proportionately to the magnitude of a reference outcome. Thus a $100 price reduction seems significant when buying a $200 pen (a saving of $100/$200 or 50%), but trivial when buying a $20,000 car (a saving of only $100/$20,000 or half a percent). Thaler (1980) subsequently labeled this phenomenon "percentage-framing". Whereas outcome framing relative to a reference point (Kahneman & Tversky, 1984) involves a difference operation, the percentage framing of outcomes involves a ratio operation. Such ratio comparisons are not just restricted to human comparisons of money savings. Gallistel and Gelman (1992) review a large amount of evidence that suggests that rats' comparisons of numerosities involve ratio operations and that animal number and duration discrimination conforms at least qualitatively to Weber's law.

Weber, Shafir and Blais (2003) have argued that the coefficient of variation (CV), a measure of the *relative* variability of risky choice alternatives might therefore be a better predictor of risk sensitivity than the unstandardized variance or standard deviation. The CV is defined as the standard deviation of outcomes divided by their mean, and often multiplied by 100, to express the standard deviation as a percentage of the mean. The CV is widely used as a measure of relative risk—risk per unit of expected returns—in applications that include engineering (e.g., Abacus Technology Corporation, 1996), medicine (e.g., Dartmouth Atlas of Healthcare in Michigan, 2000), agricultural economics (e.g., Johnson, Williams, Gwin, & Mikesell, 1986), and financial management (Gunther & Robinson, 1999; Rajgopal & Shevlin, 2000). Monitoring systems that evaluate human performance or the performance of physical systems (e.g., manufacturing processes, radon measurement) use the coefficient of variation as their preferred measure of the system's precision, often calling it the relative standard deviation (Rector, 1995). Thus it is surprising that, until very recently, it has not been examined as an index of perceived risk in risky choice.

Especially when decision makers acquire information about the distribution of possible choice outcomes by repeated personal experience (as opposed to receiving a numeric or graphic description or summary of it; see Hertwig, Barron, Weber & Erev, 2002), risky choices are far better described and predicted by a risk—return model that uses the coefficient of variation as its measure of (relative) risk than the variance or standard deviation (as a measure of absolute risk). Rabin (2000) recently called attention to the inconsistency of risk attitudes inferred from choices between lotteries and sure-thing options at different scales, under the assumption that risk preference follows a model like expected utility or prospect theory, showing in particular that degree of risk aversion computed from small stake choices vastly (and ludicrously) over-predicts risk aversion for larger stake lotteries. While a variety of post-hoc explanations have been proposed to explain empirical choice patterns that deviate from utility-function based predictions, risk—return models of choice that use the CV as their measure of risk very naturally predict such "inconsistency" in risk attitudes for choices that differ vastly in expected value.

Summary and Conclusions

Psychophysics provides two take-aways for models of risky choice. First, perceived risk appears to be subjective and, in its subjectivity, causal. That is, people's behavior is mediated by their perceptions of risk. Secondly, risk perception, like all other perception, is relative. We seem to be hardwired for relative rather than absolute evaluation. Relative judgments require comparisons, so many of our judgments are comparative in nature even in situations where economic rationality would ask for an absolute judgment. Closer attention to the regularities between objective events and subjective sensation and perception well documented within the discipline of psychophysics may provide additional insights for the modeling of economic judgments and choice.

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[i] For example, twenty-one of the explanations provided for the 25 anomalies collected by McFadden (2000) fall into these two categories.