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PROBABILITY MATCHING AND THE LAW: A BEHAVIORAL CHALLENGE TO LAW & ECONOMICS

by

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Probability Matching and the Law: A Behavioral Challenge to Law & Economics

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Abstract

Contrary to the conventional assumption that individuals maximize payoffs, robust experimental studies show that individuals who face repeated choices involving probabilistic costs and benefits often make sub-optimal decisions by applying the strategy of "probability matching." The following study, by integrating this literature with the traditional models of law and economics, and through experimental illustration, presents the possible effects of probability matching in the legal context. The paper also explores how probability matching can guide policy making.

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<u>Introduction</u>

Both criminals and tortfeasors incur costs of a probabilistic nature. In the case of criminal behavior, the criminal incurs a cost only if caught and prosecuted. In cases of negligence, a tortfeasor incurs a cost only if damage materializes. Determining whether a rational, utility-maximizing individual is likely to commit a crime or a tort requires knowledge of four variables: the benefit the perpetrator gains from her behavior, the size of the expected cost, the probability that the cost will materialize, and the perpetrator's attitude towards risk. Given these four factors, traditional law and economics suggests that individuals will act in a way that maximizes their utility.

This article, relying on experimental literature, challenges this assumption. It demonstrates that individuals, faced repeatedly with a choice involving probabilistic costs or benefits, often use the sub-optimal strategy of "probability matching." For example, a driver who is repeatedly faced with the choice of whether to cross an intersection illegally will not act as predicted by the standard cost-benefit calculations, but will rather act as a "probability matcher." Despite individuals' inclination under such circumstances not to maximize their utility, this literature shows that their decisions are not erratic, and consequently it provides the policy maker with the tools to predict and shape behavior.

The analysis has both descriptive as well as normative ambitions. Descriptively, it challenges a dominant tradition in law and economics – the tradition that individuals faced with probabilistic costs and benefits are expected to maximize their utility. Normatively, the article challenges some of the most established recommendations of law and economics in the areas of law enforcement, sentencing policy, and tort law.

This article is divided into four sections. Section I provides the theoretical background. It presents the robust findings of the experimental literature concerning probability matching. Probability matching is the term used by experimental economists and psychologists to describe the behavior of individuals who repeatedly face choices involving probabilistic costs and benefits. Probability matching suggests that, when repeatedly faced with such choices, individuals do not act in a way that maximizes their utility. Rather, they adopt a "mixed strategy," in which they make sub-optimal choices dictated by the probability of the costs or benefits. Section II explains the relevance of probability matching to the legal context. It illustrates how the predictions of probability matching differ from the predictions of traditional law and economics. It also explores some normative implications of probability matching. In particular, it demonstrates that an optimal enforcement system ought to take into account the behavior predicted by probability matching. Section III shows how certain legal doctrines can be explained by individuals' disposition to adopt the strategy of probability matching. It also shows how probability matching sheds light on persistent debates between different liability schemes. Finally, the Appendix describes an experiment designed to illustrate the effects of probability matching in a legal context. This experiment—the "traffic warden experiment"—demonstrates that individuals facing a repeated choice of whether to violate a parking regulation do not act in a way that maximizes their payoffs. Instead, they manifest behavior patterns that fit the predictions of probability matching. In sum, probability matching provides an intelligible framework within which to articulate the common accusation that human beings do not always act as maximizers and, at the same time, to account for this behavior in a way that is conducive to the legal regulation of behavior.

I. Probability Matching: Theoretical Background

Assume that you are given a die with 4 red faces and 2 white faces. You are told that the die will be rolled 100 times. You are also told that if you correctly predict the color of each roll, you will receive a reward—$10 for a correct "red" guess and $10 for a correct "white" guess. What would one do under these circumstances? What ought one to do under these circumstances?

The "maximization rule"—the rule that maximizes the expected value of the awards—would require participants to choose the red color in all 100 rolls. Yet, subjects participating in such a game who were asked to evaluate alternative strategies often preferred a mixed approach.[1] According to this strategy, bets are divided so that red is

[1] For studies reporting such results, see, for example, Richard F. West & Keith E. Stanovich, *Is Probability Matching Smart? Associations Between Probabilistic Choices and Cognitive Ability,* 31(2) MEMORY & COGNITION 243 (2003); (finding that most college students participating in a die-rolling experiment rejected the maximization rule and instead applied the strategy of "probability matching"). Ido Gal &

chosen in 2/3 of the rolls and white in 1/3 of the rolls.[2] Psychologists and economists have labeled this phenomenon "probability matching." Probability matching can be defined as the disposition to adopt a mixed strategy dictated by the relative frequency of events, even when the utility-maximizing strategy would be to always behave in a way that presupposes that the most probable event would occur.[3]

"Probability matching" suggests that there is a difference between the behavior of participants in a single-shot game and cases involving repeated games. In a single roll of a die with 4 red faces and 2 white faces, individuals consistently pick the red color. In contrast, when presented with a repeated game involving many rolls of the die, subjects do not simply make decisions as if each game is independent. Instead, their guesses are guided by the ratio of relevant probabilities and, consequently, they adopt a mixed strategy. Put differently, while in a one-shot game with a binary choice individuals are expected to maximize their prospects of success, in repeated choice scenarios they will behave in a sub-optimal manner.[4]

Probability matching has been extensively documented in the experimental literature.[5] Several tens of experiments have shown that participants consistently deviate

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Jonathan Baron, *Understanding Repeated Simple Choices*, 2 THINKING AND REASONING 81 (1996) (reporting that a substantial number of participants did not opt for the maximization rule).

[2] Choosing the red color for all 100 rolls produces, on average, 66.6 correct red guesses. The "probability matching" strategy, in contrast, provides 44.4 correct red guesses (2/3 × 2/3) and 11.1 (1/3 × 1/3) correct white guesses, for a total of only 55.5 correct guesses.

[3] The fact that participants fail to maximize their payoffs in the repeated choice scenarios has attracted the attention of rational choice theorists. Kenneth Arrow, for example, noted that "We have here an experimental situation which is essentially of an economic nature in the sense of seeking to achieve a maximum of expected reward, and yet the individual does not in fact, at any point, even in a limit, reach the optimal behavior." Kenneth J. Arrow, *Utilities, Attitudes, Choices: A Review Note*. 26 ECONOMETRICA 1 (1958). For a recent critique of the phenomenon from the perspective of rational choice, see Nir Vulkan, *An Economist's Perspective on Probability Matching*, 14 JOURNAL OF ECONOMIC SURVEYS 1 (2003).

[4] This difference in individuals' behavior patterns was recently illustrated by Birnbaum & Wakcher. In their study, Birnbaum & Wakcher showed participants several hundred simulations of races involving two horses. One horse was proven to be more successful, although the other horse prevailed occasionally. Subsequently, participants were asked to predict which of the two horses was likely to win in each of the next 100 races. Results indicated that most participants did not bet consistently on the more "successful" horse, but rather followed the strategy of "probability matching." In contrast, when asked to make one final prediction concerning the last race, almost all subjects chose the "successful" horse. See Michael H. Brinbaum & Sandra V. Wakcher, *Web-based Experiments Controlled by JavaScript: An Example from Probability Learning*, 34(2) BEHAVIOR RESEARCH METHODS, INSTRUMENTS, & COMPUTERS 189, 196 (2002).

[5] *See, for example*, Edmund Fantino & Ali Esfandiari, *Probability Matching: Encouraging Optimal Responding in Humans*, 56 CANADIAN JOURNAL OF EXPERIMENTAL PSYCHOLOGY 58 (2002) (stating that

from the maximization rule.[6] In one of the classical experiments, duplicated many times, participants observed a long series of flashing lights, some of them green and others red. The flashing lights appeared on the screen randomly, but such that 70% of the flashing lights were green and 30% red. At the end of an initial session in which the lights were shown, participants were asked to guess the color of each of the next 100 flashing lights. Consistent with the probability matching phenomenon, 70% of the time participants predicted that the next flashing light would be green, and 30% of the time that it would be red. Participants were capable of observing the probability of the lights, but failed to pursue the optimal strategy—the strategy most likely to maximize their payoffs. Instead of always choosing green and thus guessing correctly in 70% of cases, they adjusted their answers to the relative frequency of the events.

Studies indicate that subjects apply "probability matching" for gains as well as for losses. For example, in one version of the flashing lights experiment, participants were given monetary rewards for every correct guess. In another form of the experiment, subjects were granted a certain amount of money as an endowment, and a fine was imposed for every incorrect answer. The results showed that, in both instances, individuals correctly observed the probability of each color, but failed to adopt the rule that maximizes their prospects of guessing correctly. Instead, subjects consistently

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"[p]robability matching is an extremely robust phenomenon"). Furthermore, probability matching has also been observed in animals. For a survey of the literature, see, for example, CHARLES. R. GALLISTEL, THE ORGANIZATION OF LEARNING, Ch. 11 (1990) (discussing animals' experiments demonstrating probability matching behavior).

[6] For an overview of the literature see, for example, Jerome L. Mayer, *Probability Learning and Sequence Learning*, 171-205 HANDBOOK OF LEARNING AND COGNITIVE PROCESS: APPROACHES TO HUMAN LEARNING AND MOTIVATION (William K. Estes ed. 1976). While probability matching has been extensively documented, several studies have indicated that it may decrease (although not be eliminated) under some circumstances. It was shown, for example, that after a very large number of trials, some individuals' asymptotic performance exceeds the results predicted by probability matching. High monetary rewards/fines for correct/incorrect guesses were also shown to induce individuals to perform better. *See* Nir Vulkan, *An Economist's Perspective on Probability Matching*, *supra* note 3. Nevertheless, even under such circumstances, individuals often "match probabilities" rather than apply the maximization rule. In fact, in some studies monetary payoff caused participants to perform worse than participants who did not play for real money. For experiments in which participants preformed sub-optimally despite monetary payoffs and large number of trials, see Alice F. Healy & Michael Kubovy, *Probability Matching and the Formation of Conservative Decision Rules in a Numerical Analog of Signal Detection*, 7 JOURNAL OF EXPERIMENTAL PSYCHOLOGY: HUMAN LEARNING AND MEMORY 344 (1981); Hal. R. Arkes & Robyn M. Dawes, *Factors Influencing the Use of a Decision Rule in a Probabilistic Task,* 37 ORGANIZATIONAL BEHAVIOR AND HUMAN DECISION PROCESSES 93 (1986); Daniel Friedman & Dominic W. Massaro, *Understanding Variability in Binary and Continuous Choice*, 5(3) PSYCHONOMIC BULLETIN & REVIEW 370 (1998).

followed the "probability matching" strategy. Similarly, experiments involving both rewards for correct guesses together with penalties for incorrect guesses have indicated that participants acted as "probability matchers."[7] Finally, the distribution of probabilities was also found to have no bearing on the participants' behavior. Whether the proportion between green and red lights was 90% to 10%, or whether the proportion was 60% to 40%, proved to be insignificant. In all cases subjects failed to maximize; their prediction of the subsequent flashings corresponded to the observed probability of each color.[8]

Additional experiments show that individuals react in a similar manner when confronted with asymmetrical payoffs. In such cases, the rates at which subjects choose each option are equal to the corresponding expected gain. Rather than simply following the probability of each event, participants also adjust for the different payoffs.[9]

In a study conducted by Edwards,[10] for example, participants were requested to predict which of two lights ("left" or "right") would be turned on in a game involving

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[7] *See, for example*, P. SUPPES & R. C. ATKISON, MARKOV LEARNING MODELS FOR MULTI PERSON INTERACTIONS (1960) conducting three similar experiments differing only in the payoff and penalty given for correct and incorrect guess. In the first experiment, 1 cent was given for a correct guess and 0 for an incorrect guess. In the second experiment, 5 cents were given for a correct guess and a penalty of 5 cents for incorrect guess. Finally, in the third format of the experiment, a correct guess was worth 10 cents and an incorrect guess triggered a penalty of 10 cents. In all three variations subjects generally applied the strategy of probability matching rather than the maximization rule. Subjects' use of the "matching" strategy was similarly demonstrated by other experiments in which a penalty for incorrect guesses was the only payoff (that is, correct guesses triggered no reward and no penalty). *See* Vulkan, *supra* note 6 at 9.

[8] *See* William. K. Estes & J. H. Strughan, *Analysis of A Verbal Conditioning Situation in Terms of Statistical Learning Theory*, 47 JOURNAL OF EXPERIMENTAL PSYCHOLOGY 225 (1954) (reporting the use of the probability matching strategy in experiments in which probability distribution was rather extreme, that is, low probability for the less frequent option (15%) and high probability (85%) for the more frequent option); Myers et al. *Differential Memory Gains and Losses and Event Probability in a Two-Choice Situation*, 66 JOURNAL OF EXPERIMENTAL PSYCHOLOGY 521 (1963) (similarly observing the application of probability matching when the distribution of the probabilities for the two binary options was almost balanced (60% vs. 40%)).

[9] This is known as the "matching law," which is expressed by the following equation:

$$\frac{R1}{R1+R2} = \frac{r1(A)}{r1(A)+r2}$$

Where $R\mathbf{1}$ represents the rate of responding on one response alternative and $R\mathbf{2}$ represents the rate of responding on a second alternative; $r\mathbf{1}$ and $r\mathbf{2}$ represent the respective rates of payoff for those alternative; and A represents the amount by which the payoff for one alternative differs from the amount of the payoff for the other alternative. *See generally* MICHAEL DAVISON & DIANE MCCARTHY, THE MATCHING LAW: A RESEARCH REVIEW (1988).

[10] Ward Edwards, *Reward Probability, Amount, and Information as Determiners of Sequential Two-Alternative Decisions*, 52 JOURNAL OF EXPERIMENTAL PSYCHOLOGY 177 (1956).

multiple rounds.[11] Participants were awarded real money for every correct guess, yet payoffs were asymmetric. The reward for a correct "right" guess was three times the reward for a correct "left" guess (6 cents & 2 cents, respectively). Analysis of the last 50 rounds—after participants had observed and learned the relevant probabilities—showed that participants "matched" their guesses, while taking into account the different rewards.[12] For example, in one version of the experiment, the probabilities of each light were equal (that is, each light was on in 50% of the cases). Although maximization required opting consistently for the "right" guess—considering its higher payoff—subjects adopted a mixed approach. Following the expected reward for each guess, participants distributed their guesses in a 3:1 ratio. For every three "right" guesses, they entered one "left." A similar sub-optimal pattern was observed for different probabilities ratios.[13]

Signal detection and prediction of die rolling are rather artificial environments. Yet probability matching also occurs in more natural settings, representing more realistic everyday dilemmas.[14] For example, in a series of studies, participants were asked to assume the role of medical practitioners making a series of diagnoses.[15] Subjects initially learned the correlation between certain symptoms and the likelihood of a disease. Subsequently, participants were presented with the description of the symptoms of several patients. To maximize the probability of correct diagnoses, participants should have consistently chosen the outcome (disease/not disease) more frequently associated with that particular symptom pattern. Participants, however, made judgments that were

[11] For a detailed description of the experiment design, see *id.*, at 177-78.

[12] *Id.*, at 180-83. Edwards' study involved several experimental groups, differing in the information and type of feedback given to the participants. Neither of the groups, however, applied the maximization rule, although some participants performed somewhat better than predicted by "probability matching." *Id.* The results to which we refer are those of the group under the typical condition of probability matching experiments, namely, a repeated choice involving two binary, independent options (group "OL").

[13] For example, with these same payoffs, when the ratio between the "left" and "right" was set to 70% and 30% respectively, participants chose "left" roughly in 47% of the time. Such a rate corresponds to the relative expected payoff for each guess (70% × 2 = 1.4 cents, 30% × 6 = 1.8 cents). Sub-optimal behavior was also observed when the ratio for the "left" light was increased to 80% and 90%. *Id.*

[14] For a general overview, see Wayne W. Fisher & James E. Mazur, *Basic and Applied Research on Choice Responding*, 30 JOURNAL OF APPLIED BEHAVIOR ANALYSIS 387 (1997)

[15] For example, see the description of these studies in David Friedman et al., *A Comparison of Learning Models*, 39 JOURNAL OF MATHEMATICAL PSYCHOLOGY, 164 (1995).

guided by the ratio of probabilities. In one study, for example, one particular symptom pattern predicted a disease with 78% probability. To maximize the probability of correct diagnoses, participants should have diagnosed any person with the relevant symptoms as suffering from this particular disease. Yet participants in this experiment attributed the disease to only 75% of the cases involving these symptoms.[16]

The robustness of the probability matching phenomenon is further indicated by its occurrence even when the subject is cued about the correct strategy to pursue. For example, in one version of the flashing lights experiments, subjects were instructed that winning the game requires guessing correctly only 75% of the time. During the initial session, green lights were shown 75% of the time. Nevertheless, subjects continue to adopt a mixed strategy.[17] For every several greens, subjects occasionally guessed red. Similarly, even explicitly informing the subjects of the exact probabilities increased the number of correct guesses but did not lead participants to adopt the maximization rule.[18]

Why do people prefer to adopt the probability matching strategy to the maximization rule? One can only speculate, but it seems that the explanation is partly grounded in the instinctive wishes of participants to prefer a strategy that can guarantee full success (with very little probability) over a strategy that would yield a relatively large number of correct guesses, but would inevitably lead to some errors. [19] Choosing "red" in all 100 rolls guarantees a large number of correct guesses, but inevitably produces wrong

[16] *See* David R. Shanks, A *Connectionism Account of Base-Rate Biases in Categorization,* 3 CONNECTION SCIENCE 143 (1991).

[17] *See* Fantino & Esfandiari, *supra* note 5 at 62. See also Arkes & Dawes, *supra* note 6 at

[18] *Id*. *See also* Michael H. Birinbaum & Sandra W. Wakcher, *supra* note 15 at 197 (concluding from their results that despite "explicit instructions concerning the optimal strategy, accompanied by information about the probability of events … [participants'] performance still falls well short of optimal behavior"). For another well-known experiment, see Richard C. Nies, *Effects of Probable Outcome Information on Two-Choice Learning*, 64 JOURNAL OF EXPERIMENTAL PSYCHOLOGY 430-33 (1962) (reporting that providing participants the exact probability for each possible outcome made only 4 of the 192 participants to attain the optimal strategy of always predicting the more likely event).

[19] *See* Arkes & Dawes, *supra* note 6 at 94 (explaining that individuals avoid adopting strategies that are "blatantly imperfect," securing, for example, a hit rate of 70%, even if any other strategy is statistically inferior). Several studies have suggested that subjects, even if told that the sequence is random, tend to believe there is a pattern. Probability matching occurs because "[a]ny reasonable pattern hypothesized by the subjects would have to match frequency if it were to be a correct hypothesis." George Wolford et al., *The Left Hemisphere's Role in Hypothesis Formation*, 20. RC64 THE JOURNAL OF NEUROSCIENCE 1 (2000). *See also* Fantino & Esfandiari, *supra* note 5 at 59 (suggesting that probability matching occurs because "subjects in probability-matching task are attempting to devise a strategy in which they are correct or close to 100% of trials").

guesses about 1/3 of the time; after all red is expected to appear in only 2/3 of the rolls. Using probability matching (that is, guessing red in 2/3 of the rolls and white in 1/3) can yield, even if the chances are small, 100 correct guesses.[20]

Some scholars have argued that probability matching might actually be a rational strategy.[21] Using insights from game theory, it has been shown that opting for the less frequent event can be efficient in competitive environments with multiple agents. Assuming the payoff is constant, because it is expected that most subjects will choose the more frequent event, this payoff will be distributed among many. In contrast, choosing the less frequent event promises the decision maker the whole payoff, undivided, when it materializes.[22] Consider, for example, the die-rolling experiment. If the game is conducted with multiple players who split the prize, it can be rational to occasionally select "white" rather than "red." Although "white" is the less frequent event, since most players choose "red," each will receive only a small part of the prize. A decision maker choosing "white," however, is more likely to receive the prize alone, which may more than compensate for the reduced chances of winning. As such, the wide application of the probability matching strategy can be viewed as a rule of thumb, appropriate to many of the environments in which individuals interact. Some environments, however, are not competitive. In such environments, application of the maximization rule would have produced better results.

II. Probability Matching and Law Enforcement

The last section demonstrated that individuals facing a *repeated* choice involving *probabilistic* costs or benefits often behave as "probability matchers" rather than as "maximizers." Probabilistic costs are characteristic of law enforcement. Because it is

[20] The fact that young children tend to perform better than adults in probability matching experiments also suggests that the phenomenon occurs because adults wrongly believe that they can somehow guess the pattern and maximize their payoff. *See e.g.*, Peter L. Derks & Marianne L. Paclisanu, *Simple Strategies in Binary Prediction by Children and Adults,* 73 JOURNAL OF EXPERIMENTAL PSYCHOLOGY 278 (1967).

[21] *See e.g.*, GERD GIGERENZER, ADAPTIVE THINKING: RATIONALITY IN THE REAL WORLD 204-06 (2000) (arguing that while the maximization rule is efficient in social isolation, probability matching can be the optimal strategy in many contexts involving social interaction).

[22] *See, e.g.*, CHARLES. R. GALLISTEL, THE ORGANIZATION OF LEARNING *supra* note 5 at 352-53 (explaining that probability matching can be the most efficient strategy in competitive environments.)

impossible to place a police officer next to every stop sign or to inspect each potentially polluting factory, the imposition of criminal sanctions is inevitably probabilistic. Probabilistic costs also characterize tort law; even when detection is certain, it is often the case that the actual infliction of harm is probabilistic.

Potential criminal-related behaviors and tort-related activities are in many cases, although not always, of a repetitive nature. Drivers face the choice of whether to illegally cross the same intersection, and polluters face the choice of whether to pollute, repeatedly.[23] As such, probability matching has important implications concerning optimal law enforcement policy. This section is devoted to examining the ways in which probability matching can improve and enrich policy-making in the context of criminal law and tort law.

To illustrate, consider this example: assume that the police wish to deter drivers from crossing an intersection illegally. The only sanction for crossing the intersection illegally is $100, and the benefit of crossing it illegally without being caught is also $100.[24] Assume, in addition, that drivers cross the intersection repeatedly. Finally, assume that a police car can be placed such that drivers who cross the intersection cannot see it in advance. Thus, the drivers' behavior is determined solely by the sanction and by the subjective probability they attribute to the placing of the police car in the intersection.

Under the predictions of traditional law and economics, if drivers are risk neutral, it is sufficient to place the police car in 51% of the cases (or at least to make drivers believe that it is there in 51% of the time). This guarantees that it would be irrational to cross the intersection illegally since the expected costs of crossing illegally are higher than its expected benefits.[25] Placing the car less than 51% of time is wasteful because drivers would never stop; placing the car more than half of time is inefficient since the same deterrence can be achieved with less investment.

[23] It may be argued that, in the real world, under less sterile conditions, individuals do not treat repeated choices as part of one sequence. We address this concern later. *See* text accompanying *infra* note 33.

[24] Similarity of payoffs is assumed for arithmetic convenience. When payoffs are not equal, probability matching follows the "matching law." *See supra*, note 9.

[25] The benefit from crossing the intersection illegally, if not caught, is $100. If the police officer is placed 51% of the time, expected benefit is $49 ((100% – 51%) × $100). The sanction for illegally crossing the intersection, if caught, is $100. If the police officer is placed 51% of the time, expected cost is $51 (51% × $100). Placing the police officer 51% of the time makes it unprofitable for the drivers to illegally cross the intersection.

Probability matching suggests otherwise. Placing the police car 51% of the time would cause drivers to cross the intersection legally in roughly 51% of the cases. Increasing the presence of the police car to 70% of the time would therefore increase law-abiding behavior. If the differential cost of placing the police car in 70% rather than 51% of the time is sufficiently low, it may be desirable on the part of the police to make this investment.[26]

To illustrate the relevance of probability matching to optimal investment in law enforcement, consider the following case. Assume that 500 vehicles cross the intersection every day. Assume that a car crossing the intersection illegally imposes an expected social cost of $1. Finally, assume that the marginal costs of placing a police officer in the intersection increase in the following way:[27]

Days on Which a Police Officer is Placed	Marginal Enforcement Cost	Total Enforcement Costs
First day	$100	$100
Second day	$400	$500
Third day	$1500	$2000
Fourth day	$3000	$5000

Traditional law and economic analysis would suggest, under these circumstances, that it is irrational (assuming that the drivers are risk-neutral) to place a police officer in the intersection. As drivers' costs from crossing the intersection illegally are equal to their benefit, they will cross the intersection illegally unless it is more likely than not that they would be caught. Therefore, deterrence will be achieved only if a police officer is placed at least 4 days a week (more than 50% of the time). In weekly terms, this would indeed save $3500 in social costs (7 × $500), but would require investing $5000 (100 + 400 + 1500 + 3000) in enforcement. Any attempt to place a police officer less than four

[26] This result, as predicted by probability matching, is based on the assumption that individuals are risk neutral. Once risk aversion is taken into account, the prediction would be different and would be determined both by attitudes to risk as well as by probability matching. For a more thorough discussion of this point, see Appendix.

[27] Increasing marginal costs of enforcement may result, for example, from the need to pay extra-hours when police officers work more, or from recruiting additional personnel with higher opportunity costs.

days would be a waste of money, as drivers would not be deterred from crossing the intersection illegally.

In contrast, if people are "probability matchers," placing a police officer for two days would be efficient. Every day that a policeman is placed deters five hundred vehicles from crossing the intersection illegally, saving $500 in social costs. Drivers, noting that the police officer is present one-seventh of the time, will obey the light at the same rate – one day a week. Given that the costs of placing a police officer for a first and a second day are each lower than $500, a policymaker ought to place a police officer in the intersection for two days.

This example illustrates that a policymaker relying on the predictions of probability matching may invest more in enforcement than a policymaker relying on the conventional economic analysis of law. A small alteration of the assumptions can also illustrate that probability matching can justify a lesser investment in enforcement.[28]

In the last example it was assumed that social costs produced by criminal behavior (crossing the intersection illegally) remains fixed for every car. In some contexts, however, the marginal social cost generated by illegal behavior is expected to increase with additional levels of the activity. Under such conditions, even if one assumes that marginal enforcement costs are fixed, probability matching may again recommend a different policy than that mandated by conventional law and economics.

Consider, for example, the dumping of toxic materials. Assume that the marginal social harm is increasing with every additional unit of dumping. While one unit of toxic material is harmless, the second unit causes a harm of $100; the third unit causes harm of $200, and so forth. To illustrate, assume that there is a factory which produces the same unit of toxic materials each day, seven days a week.[29] Assume also that the only sanction

[28] Assume that the expected social cost of a car crossing the intersection illegally is $2 rather than only $1. Traditional law and economics, under this condition, supports the placement of the police officer. Placing the police officer for 4 days would deter drivers from crossing the intersection illegally. As such, $7000 ($500 \times 2 \times 7$) in social costs would be saved, outweighing enforcement costs ($5000). Probability matching, however, indicates that the police officer should be placed for only 2 days. Because enforcement costs of the third and fourth days are $1500 and $3000 respectively, such enforcement is inefficient given that the social cost saved for each day is only $1000 ($2 \times 500$).

[29] Probability matching studies have focused on individuals, not corporations. Corporations may be better at achieving optimal maximization, and may not behave as probability matchers. The example is merely illustrative of contexts in which the marginal costs of an illegal activity increase with every additional level of activity.

for each instance of illegal dumping is $100 and that the factory gains $100 from each instance of undetected dumping. Finally, assume that the cost of employing a detection team to identify illegal dumping is $550 a day. The following table describes the marginal and total social costs resulting from illegal dumping.

Number of Instances of Illegal Dumping a Week	Marginal Social Costs	Total Social Costs
1	$0	$0
2	$100	$100
3	$200	$300
4	$300	$600
5	$400	$1000
6	$500	$1500
7	$600	$2100

Under these circumstances, traditional law and economic analysis would recommend no enforcement. Because the benefit of the factory from illegal dumping is equal to its cost, the factory would dump only if it is more likely than not that it would not be caught. Deterrence, therefore, would be achieved only if a detection team is employed at least 4 days a week. In weekly terms, operating the detection unit saves $2,100 in social costs, but would require investing $2200 ($550 × 4) in enforcement. Any attempt to employ the detection unit less than 4 days would be a waste of money, as the factory would not be deterred from dumping its toxic materials.

Probability matching, in contrast, mandates operating the detection unit once a week. Such a level of enforcement is expected to induce the factory to refrain from dumping one out of every seven times; the factory would dump only six times rather than seven. Consequently, $600 would be saved, which outweighs the enforcement costs ($550). A small change in the assumptions can illustrate that probability matching may also justify a smaller investment in enforcement than that demanded by conventional economic analysis.[30]

To sum up, the preceding analysis demonstrates that if either the social cost of illegal activity or the costs of enforcement (or both) are not constant, probability matching and traditional economic analysis may support different enforcement policies. Differences may cut both ways: probability matching may justify both higher as well as lower enforcement levels than suggested by conventional law and economics.

Individuals' inclination to favor the strategy of probability matching over the maximization rule has been primarily demonstrated in experimental settings. In order to establish the relevance of probability matching to the legal context, one needs to examine the behavior of individuals in the actual world.

There are several factors that may suggest that probability matching has only limited relevance to legal contexts. First, individuals may not always be aware of the probabilities of detection or the size of the sanctions. It is possible that probability matching does not occur in contexts involving significant uncertainty. Second, legal contexts may involve cases in which the probability of the materialization of the cost or

[30] Assume that the marginal social costs of illegal dumping increase more rapidly, so that the first unit of dumping is harmless, the second unit causes harm of $150 (rather than $100), the third unit causes harm of $300 (rather than $200) and so forth. The following table summarizes the social costs resulting from illegal dumping under this modified assumption.

Number of Instances of Illegal Dumping per Week	Marginal Social Costs	Total Social Costs
1	$0	$0
2	$150	$150
3	$300	$450
4	$450	$900
5	$600	$1500
6	$750	$2250
7	$900	$3150

Traditional law and economics, under this condition, supports the employment of the detection unit. Operating the detection unit for 4 days would deter the factory from illegal dumping. As such, $3,150 in social costs would be saved, which outweighs enforcement costs ($550 × 4). Probability matching, however, indicates that the detection unit should be employed for only 3 days. Employing the detection unit for an additional day costs $550, but would save only $450 in social costs.

benefit is small. In contrast, most of the probability matching experiments involved probabilities of intermediate size. Studies have shown that individuals misconceive the likelihood of events with small probabilities.[31] As such, it is unclear whether probability matching also occurs in this range of probabilities. Third, the experiments involved a clear repetitive choice, presented many times during a short period. As the results show, individuals lump their decisions together as if they comprised a series. It is unclear whether people in the real world, under less sterile circumstances, perceive their repeated decisions part of one sequence. Fourth, in the actual world, individuals may possess insurance. Insurance eliminates the probabilistic nature of costs and consequently it eliminates the circumstances necessary for probability matching. Last, as the experiments of probability matching involved only individuals, it is unclear whether corporations also behave as probability matchers.

These are important concerns that may limit the applicability of probability matching or may suggest that further experimental research is required. Even so, the existing data concerning probability matching suggests that it has significant predictive power. First, when individuals have subjective convictions concerning the probability or size of sanctions, experiments have suggested that they will act as probability matchers. Moreover, in most of these experiments, participants were not told the probabilities of the events. Probability matching thus occurred despite a significant degree of uncertainty with respect to the probabilities. Subjects appeared to estimate the probabilities simply by observation.[32] Second, individuals often face probabilities of intermediate size, such as fines for traffic violations. The experiments described above are relevant to these contexts. Additional experiments are required in order to determine whether probability matching occurs in contexts involving small probabilities. Third, some experiments involved more realistic settings in which participants were presented with the repetitive choice not only in one condensed session but over several days, and under changing environments. Such circumstances come close to real life scenarios. The results show that probability matching occurred consistently, suggesting participants indeed considered

[31] *See, e.g.*, MASSIMO PIATTELLI-PALMARINI, INEVITABLE ILLUSIONS: HOW MISTAKES OF REASON RULE OUR MINDS 130 (1994) (reviewing studies showing individuals' tendency to overreact to small risks, while—at the very far extreme of the probability scale—they tend to ignore probabilities completely).

[32] *See supra*, Part I.

each decision not in isolation but rather a part of a series.[33] Fourth, insurance is not available against criminal sanctions and, even when insurance is available, not all individuals are fully insured against all types of tort or other forms of non-criminal liability. Last, more research is needed in order to examine the applicability of probability matching to corporations. Its applicability to individuals, however, is sufficient to demonstrate its importance. The experiment described in the Appendix is also designed to illustrate the relevance of "probability matching" to legal contexts.

Legal scholarship has overlooked the possible effects of probability matching concerning optimal investment in law enforcement. It has also failed to grasp how probability matching can be useful for analysis of legal doctrines. The next Part is devoted to this task.

III. Probability Matching and Legal Doctrine

A. Introduction

This Part examines legal doctrines that can be explained by the tendency of individuals to "match probabilities." It demonstrates that various legal doctrines and policies may be interpreted as designed to address inefficiencies resulting from probability matching. Section B explains the prevalence of "escalating penalties" in criminal law for repeat offenders, as well as its functional analogue in tort law—the imposition of punitive damages on "recidivist" tortfeasors. Section C provides a new rationale for regulation of socially desirable activities. Finally, section D focuses on the distinction between risk-based liability and harm-based liability systems, and provides a new rationale for some recent developments regarding liability in torts.

[33] *See e.g.*, Edwards, *supra* note 10 (reporting probability matching in an experiment involving changing probabilities, and in which participants played for 8 days with long breaks between each experimental session). Moreover, empirical studies concerning animals' behavior in nature provide further support, showing that repetitive decisions are often perceived as connected and thus subject to probability matching. *See* Gallistel, *supra* note 5.

B. Escalating Sanctions

Escalating penalties are widespread in criminal law.[34] Repeat offenders are often punished more severely than one time offenders. Under the U.S. Sentencing Commission's guidelines for punishment of federal crimes, both imprisonment terms and criminal fines are increased if a defendant has a prior record.[35] Likewise, specific statues often set higher penalties for repeat offenders. For example, hiring, recruiting, and referral violations under the Immigration Reform and Control Act impose a minimum fine of $250 for a first offense, $2,000 for a second offense, and $3,000 for subsequent offenses; in addition, "due consideration shall be given to … the history of previous violations" in setting penalties for paperwork violations.[36] Similar schemes of escalating penalties characterize the treatment of violations of environmental, health, safety, and labor regulations.[37] The legal system seems to differentiate sharply between repeat offenders and individuals who commit a crime for the first time.

Law and economics has struggled to provide a rationale for the practice of escalating penalties for repeat criminal offenders.[38] In fact, some recent theorists have

[34] *See, e.g.*, C.Y. Cyrus Chu et al., *Punishing Repeat Offenders More Severely*, 20 INT'L REV. L. ECON. 127, 127 (2000) (observing that punishing repeat offenders more harshly "is a generally accepted practice of almost all penal codes or sentencing guidelines").

[35] See UNITED STATES SENTENCING COMMISSION (1995, § 4A1.1, Ch. 5 Pt. A, and § 5E1.2).

[36] See 8 U.S.C. § 1324a(e)(4)-(5) (1997).

[37] For a detailed overview of laws applying escalating penalties, both federal and state, see David Dana, *Rethinking the Puzzle of Escalating Penalties for Repeat Offenders*, 110 YALE L. J. 733 (2001)

[38] *Id.,* at 737 ("For economists and law-and-economics scholars, however, the principle of escalating penalties based on offense history is puzzling."); Winand Emons, *A Note on the Optimal Punishment for Repeat Offenders*, 23 INT'L REV. L. & ECON. 253, 253 (2003) ("For the rather developed law and economics literature on optimal law enforcement escalating sanction schemes are still a puzzle."). For some attempts to rationale the application of escalating penalties from economic perspective, see, Moshe Burnovski & Zvi Safra, *Deterrence Effects of Sequential Punishment Policies: Should Repeat Offenders Be More Severely Punished?*, 14 INT'L REV. L. & ECON. 341 (1994); A. Mitchell Polinsky & Daniel L. Rubinfeld, *A Model of Optimal Fines for Repeat Offenders*, 46 J. PUB. ECON. 291, 303 (1991); A. Mitchell Polinsky & Steven Shavell, *On Offense History and the Theory of Deterrence*, 18 INT'L REV. L. & ECON. 305, 305 (1998); C.Y. Cyrus Chu et al., *supra* note 34. None of these attempts, however, provide a sufficient explanation. *See* Emons, at 254 (describing previous research and concluding that "[a]t the very best the literature … has shown that under special circumstances escalating penalty schemes may be optimal").

argued compellingly against the practice of imposing escalating penalties.[39] Probability matching provides a novel rationale for this practice. Individuals who face a one-time choice to commit an illegal activity tend, as the experiments demonstrate, to behave as maximizers.[40] Consequently, it is sufficient to deter them by imposing a sanction whose expected value is larger than their benefit. In contrast, individuals facing repeated opportunities to perform an illegal activity may act as "probability matchers." As such, they may occasionally choose to perform the activity even if its expected cost is higher than its expected benefit. Therefore, a higher penalty is required to incentivize "probability matchers" to refrain from violating the law. In the absence of a scheme of escalating penalties, individuals with repeated opportunities to violate the law would choose to commit the illegal behavior in accordance with the prediction of probability matching.

Arguably, the legal system could achieve the same purpose by imposing a harsh sanction for every violation, irrespective of the criminal history of the offender. Yet harsh sanctions are not costless and ought to be avoided if unnecessary.[41] First, high sanctions may overdeter. If there is a risk of accidental violation, or of an erroneous conviction, harsh sanctions deter legal behavior. Second, severe penalties eliminate marginal deterrence—the incentive to substitute less for more serious crimes. Finally, severe sanctions increase enforcement costs, such as costs resulting from long incarceration periods, or costs associated with collecting large fines. Severe sanctions, therefore, must be avoided if more moderate penalties can achieve a similar level of deterrence.

Escalating penalties serve, therefore, the purpose of deterring both one-time offenders and "probability matchers" at the lowest possible cost. The legal system applies a price discriminating mechanism under which severe (and expensive) sanctions are reserved only for individuals that cannot be deterred by moderate penalties. Setting a low initial penalty serves to deter individuals facing the choice occasionally; higher sanctions

[39] Dana, *supra* note 37 at 737 (arguing that "the economic model of optimal deterrence actually supports declining penalties based on offense history for some categories of offenses, rather than nonescalating or escalating penalties," since convicted offenders are more likely to be detected if they commit additional crimes.); Emons, *supra* note 38 at 254 (concluding that "optimal sanction scheme is decreasing rather than increasing").

[40] *See* Birnbaum & Wakcher, *supra* note 4.

[41] *See* RICHARD A. POSNER, ECONOMIC ANALYSIS OF LAW 221-23 (6th ed., 2003)

are imposed only to deter subjects who face the choice repeatedly and are likely to apply a strategy of probability matching.

The growing literature on escalating penalties focuses its attention on criminal law. It is, however, worthwhile highlighting the fact that a similar phenomenon can be found in tort law. Instead of using "escalating penalties," tort law employs punitive damages to deter "recidivist tortfeasors."

One of the considerations courts investigate in deciding whether to award punitive damages is whether the defendant is a repeat tortfeasor.[42] As the Supreme Court recently acknowledged, the question of whether the harmful conduct "involved repeat action or was an isolated incident,"[43] would be one major factor in imposing punitive damages. This principle has also been recognized by state legislation. State laws often explicitly condition the imposition of punitive damages on the defendant's recurring behavior.[44]

Probability matching can again explain this doctrine. Consider, for example, an activity that only causes harm 60% of the time. When harm does not occur, the benefit from the activity is $100. When the harm materializes, the damage from the activity is likewise $100. Setting damages to the actual harm ($100) is enough to deter risk-neutral individuals who face a one-time choice to perform the activity. If individuals face the choice repeatedly, however, such a level of compensation is insufficient. The tendency to "match the probabilities" would cause such individuals to adopt a mixed approach. Individuals would perform the risky activity six of ten times that they face the choice. Imposing punitive damages on repeat tortfeasors may serve to counterbalance the effect caused by the probability matching phenomenon.

To sum up the discussion, escalating sanctions consist of both the practice of escalating penalties in criminal law as well as the practice of imposing punitive damages

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[42] *See generally* DOBBS, *Id.*, at § 3.11(2) (noting that "[r]epeated misconduct or a policy of misconduct … is often an element in punitive damages cases").

[43] *State Farm Mut. Auto. Ins. v. Campbell*, 123 S.Ct. 1513, 1521 (2003)

[44] *See, for example*, D.C. CODE ANN. § 28-3813 (1981) (providing that punitive damages may be awarded for "repeat violations" of consumer protection laws); IDAHO CODE § 48-608 (holding that imposition of punitive damages for unlawful trade practices is conditioned on "repeated" violations); IOWA CODE § 91E.4 (holding that "an employer who, through repeated violation … demonstrates a pattern of abusive recruitment practices may be ordered to pay punitive damages"); ME. REV. STAT. ANN. tit. 22 § 2697 (providing that punitive damages can be imposed only for "repeat" violations of the law concerning profiteering in prescription drugs).

on repeat tortfeasors. Probability matching provides a rationale for the use of such sanctions.

C. Socially Desirable Behavior

The above discussion regarding escalating sanction finds a mirror image in another argument concerning socially *desirable* behavior. Probability matching indicates that individuals who face repeat choices for socially desirable activities may take risks that are too small. Consider, for example, an individual who can invest \$100 in a project that is expected to yield, with equal probability, either \$0 or \$300. Although the expected benefit from the project is higher than its costs, a risk neutral individual who faces the choice repeatedly is expected to invest in such projects only occasionally. While the individual would invest most of the time, she would occasionally forgo the opportunity, due to her inclination to "match" the probabilities. In such cases, it may be desirable to increase the expected payoff of the project to induce the individual to invest more consistently in these projects. Providing subsidies to those who repeatedly engage in such projects may, under these circumstances, bring about this result.

Another possible response of the legal system to the disposition of individuals to invest less than socially desirable in risky initiatives (even when these investments are conducive to their own interests) is by regulation. For example, regulation compelling common carriers to provide service to everybody indiscriminately can be rationalized in this way.

Consider the following case. Providing cab service to a customer is on the whole conducive to the interests of the cab driver, yet it often involves a risk. The ride in certain cases may be detrimental to the interests of the cab driver when, for instance, the road is jammed, or the destination is too remote. These existing risks may lead one to conclude that cab drivers who are prone to probability matching may fail to provide service even when providing such a service is ex-ante profitable.

Assume, for instance, that a particular road is jammed in 10% of the time, and that the occurrence of traffic jams is independent and stochastic. If there is traffic jam, the driver suffers harm of \$ 10 while, if the road is free, his benefit is \$10. Assuming risk neutrality, if the driver is a probability matcher he is likely to refuse to serve 10% of the customers. Such a refusal is detrimental to the interests of the cab driver (as well to society) because the expected payoff to the driver from each ride is $ 9.

In many jurisdictions cab drivers are required to serve all customers.[45] These regulations are sometimes aimed at combating discrimination and providing services to the disabled. Such regulations are seen as grounded in the interests of customers. Probability matching, however, suggests that such regulations may serve additional purposes. Data shows that many refusals are motivated not by racism but by the profit concerns of drivers.[46] Probability matching suggests that drivers may forgo opportunities despite the expected positive payoffs of these opportunities. As such, compelling cab drivers to provide service indiscriminately may be rationalized as a paternalistic device.

D. Risk-Based Liability versus Damage-Based Liability

This section investigates the debate concerning liability for the harmless imposition of risk—an imposition of risk that does not generate harm—in both criminal and tort law. In tort law, the question is whether liability should be imposed for negligence which does not result in harm. In criminal law, the question is whether criminal sanctions should be imposed for unsuccessful attempts. We shall argue that while numerous considerations (either justice-based or efficiency-based) should be taken into account in deciding when liability should be imposed, probability matching is an additional important consideration that justifies the attribution of liability simply for the imposition of risk. We will also demonstrate that there are indications that law is moving in this direction.

[45] *See, e.g.,* rule 2-50 (a)-(d) to Title 35 of the rules of New York City. These rules state the following: §2-50 Refusals. (a) A driver shall not seek to ascertain the destination of a passenger before such passenger is seated in the taxicab. (b) A driver shall not refuse by words, gestures or any other means, without justifiable grounds set forth in §2-50(e) herein, to take any passenger to any destination within the City of New York, the counties of Westchester or Nassau or Newark Airport.

[46] *See, e.g.*, Bruce Schaller and Gorman Gilbert, *Factors of Production in a Regulated Industry: New York Taxi Drivers and the Price for Better Service* (http://www.schallerconsult.com/taxi/taxi1.htm). This research cites a survey from 1993 which indicates that "[t]he underlying motivation in each case is financial … While white passengers cited financial motivations more often than did nonwhites, even nonwhite complainants were more likely to attribute refusals to nonracial motivations than to racial bias."

Legal systems may adopt different mechanisms for providing incentives to prevent probabilistic harm.[47] On the one hand, a legal system could impose a *risk-based liability system*, namely a system that imposes sanctions on anybody who imposes risk regardless of whether the imposition of risk resulted in actual harm. In order to provide efficient incentives, the legal system ought to impose a sanction which would equal the expected harm of the activity.

On the other hand, a legal system could adopt a *harm-based liability system*, namely a system in which only those who inflict a risk which results in actual harm are subject to sanctions. In this case, the legal system could deter wrongful behavior if it imposes sanctions that are equal to the harm resulting from the behavior of the particular wrongdoer.

Last, a legal system could adopt a *mixed (risk-harm) liability* system under which it imposes diverse sanctions. Under such a system, those who imposed risk which resulted in harm would be subject to different sanctions than those who imposed risk which did not result in harm. Let us examine how these three schemes could operate in different fields of the law.

Under a risk-based scheme, as applied to tort law, liability would be imposed for any imposition of risk. [48] The amount of compensation under a risk-based tort system would equal the *expected damage* causally related to the wrongful conduct.[49] The traditionally prevalent legal position in tort law is that liability in torts can only be

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[47] For a comprehensive discussion, see Steven Shavell, FOUNDATIONS OF ECONOMIC ANALYSIS Chap. 25 (2004); ARIEL PORAT & ALEX STEIN, TORT LIABILITY UNDER UNCERTAINTY, Chap. IV (2001).

[48] *See* PORAT & STEIN, *Id.,* at 103.

[49] If, for example, this conduct were to involve a 50% probability of inflicting damage equal to $1000, then the defendant would have to pay $500 in liability damages. Similarly, a speeding driver would pay in accordance with the expected damages resulting from her behavior irrespective of whether the harm actually materialized. Such a scheme is not merely theoretical. It has been proposed by some legal scholars primarily on the grounds that such a scheme is more just. *See, e.g.*, C.H. Schroeder, *Corrective Justice and Liability for Increasing Risks*, 37 UCLA L. REV. 439 (1990); C.H. Schroeder, *Corrective Justice, Liability for Risks, and Tort Law*, 38 UCLA L. REV. 143 (1990). For a critical response, see K.W. Simmons, *Corrective Justice and Liability for Risk-Creation: A Comment*, 38 UCLA L. REV. 113 (1990). For further corrective justice arguments see, E. Weinrib, *Understanding Tort Law*, 23 VALPARAISO L. REV. 485 (1989). One of the advantages of such a system is that it mitigates (although it does not altogether avoid) the problem of "moral luck," namely, treating differently individuals with identical culpability. For the problem of moral luck, see the recent discussion by David Enoch & Andrei Marmor, *The Case Against Moral Luck* (http://papers.ssrn.com/sol3/papers.cfm?abstract_id=475161). For a useful collection of essays, see MORAL LUCK (Daniel Statman ed., 1993).

imposed when the plaintiff has sustained damage that was wrongfully inflicted by the defendant. Nevertheless, recent developments clearly indicate greater willingness on the part of judges to attribute liability on the basis of the imposition of risk. Doctrines such as "market share liability," "loss of chance," and "evidentiary damage" allow courts to impose liability on the defendants, even if plaintiffs fail to show causal relation between the harm suffered by plaintiffs and defendants' behavior. When applying such doctrines, courts often refer to the *risk of injury* to which the defendant wrongfully exposed the claimant as the criterion for determining defendant's liability. As such, tort law is traditionally a harm-based system that increasingly recognizes risk-based claims.[50]

The question of whether to employ harm-based or risk-based liability can also arise in the context of criminal law. The legal system could impose (a relatively small) penalty on every person who attempts to commit a crime regardless of whether she succeeds or not, or it can impose (a relatively harsh) sanction only on those criminals who successfully complete the crime. Finally, it could adopt a mixed system and impose different sanctions on successful and unsuccessful perpetrators of crime.

As a matter of practice, modern criminal law adopts either the mixed system or the risk-based system.[51] A greater emphasis on criminal *mens rea* as the cardinal parameter in determining criminal responsibility has resulted in the imposition of sanctions for attempts. In some systems the sanctions imposed for attempts are more lenient than those imposed for the complete offence, while in other systems the sanctions imposed for attempts are identical to those imposed for the complete offence.[52]

[50] Consider, for example, a typical "loss of chance" malpractice claim. A doctor negligently examines a patient. Consequently, the plaintiff loses 30% of his chance of recovery and dies. Under the traditional harm-based approach, plaintiff's claim ought to be rejected. As it is more probable than not (70%) that the plaintiff would have died even if the doctor had not been negligent, the plaintiff cannot establish causation. Under the doctrine of "loss of chance," however, the doctor is liable for the risk to which she exposed the plaintiff. More specifically, she is liable for 30% of the damage. For a review of American and British tort cases in which courts imposed liability based on risk rather than actual harm, see Ariel Porat & Alex Stein, *Indeterminate Causation and Apportionment of Damages: An Essay on Holtby, Allen and Fairchild*, 23 OXFORD J. LEGAL. STUD. 667 (2003).

[51] Some commentators have noticed a transition towards reducing the gap in the sanctions imposed for attempts and completed crimes. *See* Yoram Schachar, *The Fortuitous Gap in Law and Morality*, 6 CRIM. JUST. ETHICS 12, 13 (1987).

[52] For a discussion of the treatment of attempts in criminal law, see Omri Ben Shahar & Alon Harel, *The Economics of the Law of Criminal Attempts: A Victim-Centered Perspective*, 145 U. PA. L. REV. 299 (1996).

There are many considerations that dictate whether to adopt a risk-based, harm-based, or a mixed system. A risk-based system has advantages in that it seems less arbitrary and it mitigates the "moral luck" concern. Corrective justice arguments may also support a risk-based system.[53] Nevertheless, pragmatic, efficiency-based considerations often preclude the possibility of using a risk-based (and perhaps even a mixed) system in tort law.[54] The purpose of this section, however, is not to evaluate all the pros and cons of risk-based or harm-based systems. Instead, it aims at investigating the relevance of probability matching to resolving this debate.

Assume an activity which imposes a risk that may or may not materialize. As such, this activity (which could be either a crime or a tort) generates a probabilistic cost. Under a risk-based system, assuming full detection of risky behaviors, the person who imposes a risk is always required to pay a fee that is equal to the activity's social costs. Under such a system, the agent would engage in the activity if and only if her benefit exceeds the expected cost. In contrast, under a harm-based system, the person who imposes a risk is liable only if the risk materialized and generated actual harm. From the perspective of the agent, the fee is a probabilistic cost which will be imposed only if his activity resulted in actual harm. The agent in this case would behave as a "probability matcher." Probability matching suggests that a harm-based system would lead an agent to adopt a mixed strategy in which she sometimes engages in the activity and sometimes does not, even if the expected cost of the activity is higher than its expected benefit. The deterrence resulting from a harm-based system is therefore inefficient. Optimal deterrence requires either preferring a risk-based system or imposing harsher sanctions than those demanded by traditional analysis.

Given the plurality of factors which bear on this question, it is difficult to establish that the choice of criminal law to adopt a risk-based (or a mixed system), and

[53] Effective deterrence considerations, such as taking the solvency of the perpetrator into account, may also support a risk-based approach: "[Risk]-based sanctions do not require that sanctions be as high as harm-based sanction, if the harm due to an act is probabilistic…. A party needs to have much higher assets to he deterred by the threat of sanctions for doing harm than by the threat of sanctions for committing an act, it the act causes harm only with low probability." Shavell, *supra* note 47 at 577.

[54] *See* PORAT & STEIN, *supra* note 47 at 109-10. Unlike actual damage, imposition of bare risk is largely non-observable by potential plaintiffs. Moreover, even when risk-imposition is observable by plaintiffs, it often remains unverifiable at trial.

the recent transition in tort law towards such a system, is in fact grounded in probability matching. Even so, the discussion demonstrates that, in choosing among a risk-based, a harm-based or a mixed system, probability matching may be a cardinal consideration.

For reasons briefly mentioned in the end of section II, applying probability matching to the legal context should be done with great caution. The structural similarity between the laboratory and real-life gives rise to the conjecture that probability matching is highly relevant to the legal context. Yet, such a conjecture ought to be examined empirically. This article draws attention to the potential relevance that probability matching may have in the legal context. Future work ought to explore the precise contexts in which probability matching can provide the policymaker or the legislature with guidelines for regulating behavior.

V. Conclusion

Rational choice approaches predict that individuals are expected to behave consistently in a way that maximizes their utility. As such, rational choice theory attributes behavioral changes to either objective alterations in the environments in which these individuals interact, or to alternations in individuals' preferences, beliefs or attitudes toward risks. In such cases, behavioral changes simply reflect alterations in one's objective or subjective world.[55] Reality, however, suggests otherwise. People faced with a series of decisions involving repeated choices with probabilistic costs or benefits often change their behavior despite no apparent alterations in their preferences or environments.

This gap between rational choice theories and reality, however, does not indicate that either the assumption of rationality or the hope to anticipate the behavior of individuals must be abandoned. In the special context of repeated binary choices, probability matching provides the theoretical background that is required to bring theorists' models closer to the actual world. Since legal contexts are often typified by probabilistic costs and benefits, probability matching is of special interest for legal

[55] *See, for example*, Gary Backer, *The Economic Approach to Human Behavior*, in RATIONAL CHOICE 108 (Jon Elster ed., 1986) (discussing the rational-choice assumption of behavior consistency and the reasons for behavioral alterations).

scholars. The preceding analysis, which provides several examples of the significance that probability matching may have on conventional legal analysis, is a first step in this direction.

Appendix: The Traffic-Warden Experiment

Studies demonstrating the impact of probability matching on individuals' choices have typically been conducted in contexts that do not have legal significance.[56] The "Traffic-Warden Experiment," presenting participants with a choice whether to pay a parking fee, demonstrates the phenomenon of probability matching in a legally relevant context.

There are several factors that characterize choices exercised in a legal context. First, it is typically the case that the choices involve asymmetric payoffs. The payoff of obeying the law is different than the expected payoff of disobedience. Moreover, these choices involve potential gains as well as potential losses. The following experiment combines these elements and also positions the participants in a quasi-legal setting.

Participants. A group of 102 undergraduate students from the Hebrew University of Jerusalem participated in the experiment. The participants were recruited through campus advertisements promising monetary rewards for participating in a decision making task.

Procedure. Upon arrival, each participant was given instructions concerning the task by an experimenter. All questions concerning the experiment were answered and instructions were repeated until the participants indicated that they fully understood the instructions. During the instructions, the participants learned that the task would be repeated for twenty-four experimental rounds, and that they would be paid on the basis of their decisions in each round. Participants were encouraged to think carefully about each of the decisions.

Participants were initially endowed with 10 New Israeli Shekels ("NIS") to decrease the likelihood that the more unruly participants end up having to pay the experimenter.[57] Then participants were told that they drive a van and have to drop off a package. For every delivery of a package the participant is paid *NIS* 2. Yet, prior to delivery, the participant has to park the van and decide whether to pay or not to pay the parking fee of *NIS* 1. Thus, a participant deciding to pay the parking fee earns *NIS* 1 for

[56] See the studies described in Part I.

[57] At the time of the experiment, 4.5 New Israeli Shekels were worth roughly $1.

each round. A participant who does not pay the parking fee and is not caught by a traffic warden earns *NIS* 2 for each round. Participants who decide not to pay, however, face a risk of being "caught" by a traffic warden and having to pay the fine. In order to determine whether a warden has detected the violation, participants were asked to roll a die. One face of the die was labeled "warden has come." Every time the participant is asked to "deliver a package," she must first decide whether to pay the parking fee. The die is then tossed. If it lands on the side labeled "warden has come," and the participant decided not to pay the parking fee, the participant is fined for "illegal parking." The probability of being "fined" is therefore 1/6 for each round.

The same process is repeated twenty-four times. Twenty-four was chosen because it is not too large a number such that the participants would get bored and fail to take the task seriously and it is sufficiently large such that patterns of probability matching can be detected.[58]

Design. Participants were divided into three sub-groups of 34, differing in the fine imposed for illegal parking. The fine for group A was *NIS* 3, for group B *NIS* 6, and for group C *NIS* 12.

Let us compare the results as predicted by traditional law and economics and by the more sophisticated model that takes into account the effect of probability matching. We shall first assume (unrealistically) that individuals are risk neutral. This assumption will be revised later in light of our findings.

For group A (with a fine of 3 *NIS*) the expected cost of illegal parking is *NIS* 0.5 ($3 \times 1/6$), half the cost of the parking fee (*NIS* 1). A risk-neutral individual, attempting to maximize payoffs, would therefore never pay the parking fee. For group B (with a fine of *NIS* 6), the expected cost of illegal parking is *NIS* 1 ($6 \times 1/6$), equal to the cost of the parking fee. A risk-neutral individual would therefore be indifferent between paying and not paying. For group C (with a fine of *NIS* 12) the expected cost of illegal parking is *NIS* 2 ($12 \times 1/6$), twice the cost of the parking fee. A risk-neutral individual in this group, attempting to maximize payoffs, would therefore always pay the fee.

58 Twenty four rounds may appear too little to replicate daily experience. Yet, the experiments described in the psychological literature indicate that increasing the number of rounds to several hundreds generally did not change the results. *See* references cited in *supra* note 6.

Probability matching, however, predicts different behavior. Recall the predictions of probability matching in the case of asymmetric payoffs.[59] According to this model, in group A, where the cost of paying the parking fee (*NIS* 1) is twice as much as the expected fine ($3 \times 1/6 = .5$ *NIS*), risk neutral participants are expected to pay 1/3 of the time; in group B, where the cost of paying the fee is equal to the expected cost of the fine, the prediction is that a risk neutral participant would choose to pay for parking 1/2 of the time. In group C, where the cost of paying the fee is half the expected cost of the fine ($12 \times 1/6 = 2$ *NIS*), risk neutral participants are expected to pay 2/3 of the time. Table A summarizes these predictions.

Table A

	Parking Fee	Fine for Illegal Parking	Expected Fine for Illegal Parking	No. of Rounds Fee is Paid as Predicted by L&E	No. of Rounds Fee is Paid as Predicted by Probability Matching
Group A	1 NIS	3 NIS	0.5 NIS	0	8
Group B	1 NIS	6 NIS	1 NIS	12	12
Group C	1 NIS	12 NIS	2 NIS	24	16

Results: Table B summarizes the results of the experiment. The first column denotes the mean number of times participants chose to pay the fine out of the 24 rounds. The second and the third column present the 95% confidence intervals of these means.

Results—Table B

	Pay	Lower Bound	Upper Bound
Group A	3.08	1.186	4.991
Group B	5.53	3.627	7.432
Group C	9.68	7.774	11.579

[59] *See* text accompanying note 9.

The first question is whether participants were at all sensitive to the different expected payoffs in the different fine levels.

The results clearly indicate that participants understood the game and acted in a way that is sensitive to its payoffs, namely, to the size of the fine. The participants in group A (low fine) were less willing to pay the fee than the participants in group B (moderate fine), and the participants in group B were less willing to pay than the participants in group C (high fine). The data was submitted to a one-way ANOVA,[60] with Size-of-Fine as factor. The effect of the Size-of-Fine is highly significant ($F(2,99)=12.071$, $p<.001$). Even more importantly, the linear component of the analysis contributed .998 of the variance accounted for, and was even more significant ($F(1,99)=24.09$, $p<.001$).

The second question is which of the two models – that of maximizing or that of the probability matching – better predicts the result.

Recall that, according to the maximizing model—the model that predicts that individuals will look to maximize their payoff—participants of group A should never pay the fee and participants of group C should always do so. The 95% confidence intervals appearing in Table B clearly show that neither of these predictions is met. Still, one may ask how close the actual means are to the predictions of each model. To do that, let us first look at group B.

For group B, the parking fee is equal to the expected fine for illegal parking. According to both models, risk-neutral individuals would therefore be indifferent between paying and not paying the fee. As such, if participants in Group B are risk-neutral, they are expected, on average, to pay in 12 rounds and take the risk in 12 rounds. The results, however, indicate that individuals of group B are not indifferent; instead they are more often disposed to take the risk and not pay the fee. On average, a participant in Group B paid only in 5.53 of the 24 rounds. Group B manifested, therefore, a propensity

[60] ANOVA (analysis of variance) is a statistical technique designed to test whether differences in means between experimental conditions are significant (i.e. whether it is reasonable to assume that there are real differences in the population) or whether one is able to reject with confidence the hypothesis that the means are equal (i.e. that the differences we see are just "noise" in the sample).

not to pay. The propensity not to pay may have different explanations: It may be the byproduct of playfulness on the part of participants, or a disposition for risk-seeking behavior. Irrespective, however, of what the explanations for this propensity are, it ought to be taken into account in analyzing the results in groups A and C.

Using the results observed in Group B as a rough proxy as to the degree of the disposition not to pay, it is possible to adjust the predictions of both models. To implement this adjustment, the difference between the expected 12 rounds of pay and the actual mean of 5.53 rounds (6.47) observed in Group B should be subtracted from all predictions.[61]

Table C summarizes our results and compares them with the results predicted by the two models, with and without the adjustment for the propensity not to pay. *Column 1* presents the average number of rounds the participants chose to pay. *Column 2* presents the mean number of rounds a participant would choose to pay as predicted by the maximizing model for a risk neutral individual. *Column 3* presents the means of the same model, adjusted for the observed risk taking propensity. One peculiar result of this procedure is that the number of rounds in which people would be expected to pay according to these predictions is negative in the case of group A. Since this is impossible, one would at least expect a mean of zero. Given the observed propensity of participants not to pay, it is particularly difficult for conventional law and economics based on the maximizing model to explain any decision of individuals in group A to pay the fee. *Column 4* describes the results as predicted by probability matching for risk neutral individuals. *Column 5* describes the projected outcome as dictated by probability matching, adjusted for the observed propensity not to pay.

Table C

[61] For the basis of this methodology, see generally Douglas D. Davis & Charles A. Hold, EXPERIMENTAL ECONOMICS 472-73 (1993) (discussing possible methods to obtain information regarding risk attitudes of participants).

	1	*2*	*3*	*4*	*5*
	Pay Actual	Pay Predicted by L&E	Pay Predicted by L&E and Adjusted	Pay Predicted by Probability Matching	Pay Predicted by Probability Matching and Adjusted
Group A *NIS* 3 Fine	3.08	0	-6.47	8	1.53
Group B *NIS* 6 Fine	5.53	12	5.53	12	5.53
Group C *NIS* 12 Fine	9.68	24	17.53	16	9.53

The failure of the conventional law and economics model to successfully predict subjects' behavior is manifested in the results of both Groups A and C. In Group A, traditional law and economics predicts that participants will never pay the fee. Taking into account the observable disposition not to pay—demonstrated by participants in Group B, it is particularly unlikely from the perspective of traditional law and economics that individuals would sometimes choose to pay. The results, however, indicate otherwise; participants decided to pay, on average, a little over 3 times.

As for group C, traditional law and economics predicts that participants will always pay. Given the observed propensity not to pay, traditional law and economics can perhaps explain participants' occasional decision to take the risk and avoid paying. Yet, given the fact that in Group C the expected fine for illegal parking is higher than the parking fee, participants are expected to manifest *less* (or at most *the same*) risk-seeking behavior than participants in Group B (where the expected fine equals the fee). The results, however, show the opposite. In Group B, participants decided not to pay in roughly 6 additional rounds than anticipated by the traditional model; in contrast, participants in group C chose not to pay in nearly 14 more rounds than expected by the traditional model.[62] As such, the differences between the actual results and the predictions of traditional law and economics cannot be attributed to risk seeking propensity.

The experiment results, therefore, cannot be accounted for by conventional law & economics. Participants did not maximize their payoff as the conventional model predicts. Moreover, taking into account participants' observed risk-attitude makes the model's predictions even more remote than participants' actual behavior. In contrast, the predictions of the adjusted probability-matching model (presented in column 5) closely match the experiment results (presented in column 1). As table B indicates, in all cases the actual numbers do not differ significantly from the predicted value indicated in column 5.

[62] An alternative methodology to account for the observed propensity not to pay is to form a *coefficient* corresponding to the *rate* at which participants in group B chose to pay. Participants in group B chose to pay roughly in only 5.5 rounds rather than 12, namely, in only 46% of the expected rounds. Multiplying the expected results by this coefficient (rather than subtracting the number of rounds participants in group B preferred risk over payment), however, does not alter the conclusion. Probability matching generally predicts the results better than traditional law & economics. The following table summarizes the expected results under each model adjusted according to this alternative methodology:

	1	2	3	4	5
	Pay Actual	Pay Predicted by L&E	Pay Predicted by L&E and Adjusted	Pay Predicted by Probability Matching	Pay Predicted by Probability Matching and Adjusted
Group A NIS 3 Fine	3.08	0	0	8	3.68
Group B NIS 6 Fine	5.53	12	5.53	12	5.53
Group C NIS 12 Fine	9.68	24	11.06	16	7.37

Applying this method, the results in Group A brings the prediction of the Probability Matching model even closer to the actual result. For law and economics, however, the results remain unexplainable. As for group C, the two models perform almost the same, with little advantage for the law and economics model. Still, law and economics cannot account for the observed higher propensity not to pay observed in group C in comparison to Group B. While the Group B participants paid in 5.5 rounds rather than the expected 12 (46%), the Group C participants paid in roughly 10 rounds, rather than the expected 24 (41%).