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Nonconscious cognitive reasoning: A neglected ability shaping economic behavior

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Abstract
This paper argues for the inclusion of both conscious and nonconscious reasoning in economic decision making. Vast differences in the capacities of these two sources of cognitive reasoning results in a greater reliance on nonconscious reasoning resources, although the most complex decisions depend on an automatic intermingling of conscious and nonconscious resources. Each decision resource is capable of independently processing data, determining relationships, learning about the underlying structure, and making economic decisions. In contrast to conventional analysis which implicitly views mental activity as costless, the binding limits on conscious reasoning entails high opportunity costs, and the need to make an enormous number of decisions in a timely manner in order to avoid losses due to foregone decisions. People engage in a maximization process to optimize the efficiency and accuracy of their mental resources for decision making. People choose the most efficient and least costly resources that will maximize overall utility.

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Introduction

The purpose of this articles is to advocate a basic change in how economic decisions are conceptualized, a change so fundamental that it will challenge the theories and methodologies than now dominate behavioral economics. The core of the change involves the data that are used to test hypotheses and advance theories. Rather than solely focusing on conscious cognitive decision processes, behavioral economics should also include people's nonconscious cognitive reasoning abilities. These nonconscious mental abilities process the vast majority of information that reaches people about every aspect of their personal, social and physical environments. People's nonconscious cognitive resources automatically processes, organizes, and learns about relationships in order to make more informed and accurate decisions. Most economic decisions are made and executed by people's nonconscious mental faculties. The new paradigm does not diminish the importance of conscious deliberation in decision making, but holds that people make decisions using their full cognitive capacity, both conscious and nonconscious. These faculties have benefitted from a long evolutionary development aimed at providing humans with the capacity to make effective, efficient, and timely decisions.

Behavioral economics dismissal of people's capacity to make nonconscious decisions has been due to two associated reasons. Since nonconscious reasoning is by definition unknowable even to the decision maker, investigators have held that nonconscious processes can serve no useful role in the scientific analysis of economic behavior. In contrast, the details of conscious reasoning are not only knowable to the decision maker, they are also reportable to investigators. These reports, whether verbal or behavioral, allow the characteristics of the reasoning process to be subjected to detailed examination. The limitation on the workings of the nonconscious echoes the old economist's joke about a person searching on a dark night for a lost item under a streetlight; when asked why he was searching there, he responds "because this is where the light is." Consciousness is the light that behavioral economists have huddled under for explanations of human behavior.

Many other disciplines have come to the opposite conclusion, and have long used methods to test the structure and impact of many "black boxes" whose contents are unobservable. In some fields, scientists have even specified the properties of an "unobserved variable" that was postulated as a required element for a theory to be consistent with the empirical evidence. A recent example is the *Higgs Boson*, which was finally observed a half-century after its critical role in theories of particle physics was identified.

The second reason for the lack of scientific interest is the presumption that nonconscious reasoning is more likely to be irrational than decisions made by conscious reasoning. This assertion is based on our presumed inability to examine the attributes and causes of nonconscious decisions. The presence of rationality is held to be evidence based, assessed by observing the thinking processes used to make a decision (favored in psychology) or by an examination of the outcome of the decision (favored in economics). Behavioral economists have more often adopted the psychologist's insistence on explaining the process of decision making, rather than the economist's focus on the outcomes of the decisions. Since nonconscious reasoning cannot be directly observed, it has been usually been classified by default as potentially irrational. This avoidance of the nonconscious decision processes has needlessly biased the findings given that most decisions are made at least partially, if not fully, by nonconscious cognitive reasoning. Although the irrationality of emotions can at times eviscerate rational reasoning, it is no more likely to occur when decisions are made consciously than when made nonconsciously.

Despite these strongly held views about the irrelevance of nonconscious reasoning, all too often scientists cite its critical influence in shaping behavioral decisions. Indeed, the literature seems to ascribe that most observed economic behaviors caused by the influence of heuristics, intuitions, hunches, or by simply by random guesses instead of being determined by rational choice (Kahneman, 2011; Gigerenzer, 1996). Notably, behavioral economics does not generally follow these findings with investigations about how or why people form these decision shortcuts, or how these judgement standards adapt and change over time. Many learning models have been proposed, although no learning model has yet been proposed that could guarantee a return to rational choice. Instead, behavioral economics has more commonly focused on identifying appropriate nudges that could bring about more rational decision making. Unfortunately, nudges need to be designed for specific decisions and situations, which would be an unending task given the speed of economic change.

The interdisciplinary nature of behavioral economics is required by its problem orientation. Most public policy initiatives cannot be confined to one scientific discipline, including today's premier issues of distributional equity and climate warming. These issues have deep roots in all disciplines, and their solutions will require the extraordinary merging of the best theories across disciplines. In addition to a more inclusive cross-disciplinary range, designing public policies based on behavioral economics requires that the discipline extend its coverage to include all cognitive reasoning processes. The dismissal of nonconscious cognitive reasoning represents a major loss to obtaining scientifically accurate and reliable explanations of people's economic behaviors. The substantial changes that are needed to achieve economic equity and reduce climate warming critically depend on the benefits that can be derived from the incorporation of nonconscious cognitive processes into scientific paradigms.

Many other sciences have already incorporated the influence of nonconscious processes on people's behavior. Marketing, sociology, political science, psychology, and neuroscience have long been active in this area. Even behavioral economics has been represented. Unlike other sciences, however, conscious cognitive deliberation still dominates theory to the virtual exclusion of nonconscious cognitive processes. Indeed, a good many behavioral economists find the exclusion appropriate. The exclusion has resulted in less scientific progress that would have otherwise been accomplished. The premier policy issues of economic inequalities and climate warming represent complex behavioral issues that will not be fully resolved until nonconscious reasoning becomes more accessible, integrated into behavioral theories, and commands the attention required to achieve these difficult, complex, and extensive changes in people's behaviors.

To avoid any misinterpretation, the thesis of this article is limited to people's ability to consciously and nonconsciously acquire, process, and learn about their overall environment, with the goal of making decisions that serve their best interests. Changes in their environment, whether processed consciously or nonconsciously, act to dynamically modify people's assessments and subsequent decisions. The introduction of nonconscious reasoning processes does not represent an abandonment of self-interested behavior, nor does it allow for an increased acceptance of inaccuracy or irrationality. Indeed, the cognitive resources of the conscious and nonconscious mind are seamlessly and optimally integrated when a decision is required; they do not represent opposing forces. The expanded scope of cognitive deliberation is still subject to subjective biases, emotional states, missing or inaccurate data inferences as well as many other sources of errors. The more inclusive view of people's overall cognitive capacities provide a more comprehensive explanation of the complete decision process. The main purpose of this article is to advocate deeper roots and a widening canopy of branches to foster future scholarly advancements in behavioral economics.

Cognitive reasoning ability

People's nonconscious reasoning abilities have evolved over the past six million years. In comparison, the addition of the neocortex, the region largely responsible for conscious reasoning, has a much more recent origin, appearing about two hundred thousand years ago (Massey, 2002). The much longer evolutionary development of nonconscious reasoning has meant that these capabilities are more equally shared across the population than the more recent addition of conscious reasoning. Not only is nonconscious reasoning distributed more evenly, but people's capacity for nonconscious reasoning is much larger than their more limited abilities for conscious reasoning. While the overall goals of this article represent a more ambitious task than can be accomplished in a short journal article, the basic rationale for the inclusion of nonconscious reasoning will be detailed (for a more detailed discussion, see Curtin, 2019).

The first task is to document that the human mind has vastly larger capacity to engage in nonconscious reasoning that in conscious deliberation. People's nonconscious cognitive resources are orders of magnitude larger than their conscious resources. The term cognition refers to people's mental ability to process information, interpret that information, and make decisions. These cognitive processes can occur consciously or nonconsciously, although given the capacity differences, the vast majority of cognitive activity occurs nonconsciously. The comparative costs and benefits are an important determinant of the choice people make between conscious and nonconscious reasoning. While most view the mental costs of conscious deliberation as close to zero, given the severe capacity limitations of conscious thought, the opportunity costs are far higher and more critical. Indeed, opportunity costs in large part govern which decisions are made consciously or nonconsciously.

The common assumption in economics is that it is the importance of the decision, usually measured in dollar terms, that determines whether conscious or nonconscious decision processes are used. That presumption is generally false (Camerer & Hogarth, 1999). Conscious decision processes are more frequent for first time or novel decisions or in the presence of large or discontinuous changes. Past experience is the more important factor for relying on nonconscious reasoning and nonconscious learning how past actions need to be modified. Even when decisions are made nonconsciously, the outcome of the decision process is consciously known, often described as an intuition or hunch. Nonetheless, none of reasoning or causes of the decision can be consciously recalled. People's confidence in their intuitions or hunches results from their past experiences facing similar issues. Each outcome adds to their learning and acts to reinforce or modify past responses whether decided consciously or nonconsciously.

People attempt to maximize the overall capacity of their total mental resource by choosing a balance between these two modes of reasoning. An optimal and efficient division favors shifting as many tasks as possible to their nonconscious resources, allowing their most precious mental asset of conscious reasoning to be used for their most critical decisions. Shifting between the conscious and nonconscious is automatic. No person consciously shifts a decision to nonconscious processes – although it is common for some people to describe a benefit from "sleeping on it" before making a final decision. Learning can be accomplished by either mode, as both modes can independently learn from the processed data and estimated interrelationships to make decisions. The critical difference is that people can recall conscious processing but not the processes performed by the nonconscious. The learning performed by the nonconscious is sophisticated; recent advances in econometric techniques mirror those procedures. Nonconscious processes benefit from an inherent sense of numbers and from a preference for frequencies which enables the nonconscious formation of associations and learning. Finally, the discussion turns to rational decision making of conscious and nonconscious reasoning when multiple goals are pursued simultaneously.

Allocation of reasoning resources

People are exposed to a vast amount of information each day covering every aspect of their physical, personal, political, and social environments. This information can be processed either by their conscious or nonconscious mental faculties. Most information, however, is processed nonconsciously due to the immense differences in people's conscious and nonconscious information processing capacities. The difference has been estimated to be as high as 11.2 million bits of information per second nonconsciously compared with just 40 bits of information per second consciously (Dijksterhuis, 2004; Wilson, 2002). These estimates include information processed by all human senses, and include the broad array of information needed by people to function and adjust to their surroundings. There is little doubt among cognitive neuroscientists that the capacity of the nonconscious to process information is orders of magnitude larger than by conscious acquisition of information (Lewicki et al., 1992).

Even the much larger capacity of the nonconscious cannot process to every bit of information. Selective attention is required and is shaped by people's goals and motivations. The limited capacity of conscious processes makes selective perception much more constraining, but for the nonconscious the constraints on the amount of information processed are expanded to a considerable degree. Conscious and nonconscious processing of information can occur simultaneously, allowing people to focus on a variety of information sources at the same time. One broad generalization is that novel and unexpected events are more likely to be processed consciously, and expected events are more likely to be processed unconsciously (Velmans, 1991; Curtin, 2019).

The more general underlying issue is familiar to economists: how to optimally allocate the scarce resource of conscious reasoning to best achieve desired behavioral outcomes. People selectively choose to process information either consciously or nonconsciously depending on the expected benefits and costs. The greater the potential benefit, the more likely people will use their conscious reasoning faculties. The benefits, however, must be at least as large or larger than the potential cost of conscious processing. While it has been a traditional view to assume any benefit would exceed the essentially costless use of one's own mental faculties, that assessment excludes the opportunity costs of conscious reasoning. In fact, there is a very high opportunity cost of using the very scarce resource of conscious reasoning. The conscious reasoning involved in one decision entails the cost of excluding another decision from conscious deliberation. Given that the potential demands on conscious reasoning are enormous, opportunity costs dominate priorities.

The effortful nature of conscious deliberation also provokes greater limitations on its use given that people quickly tire and abandon the exertion, allowing the nonconscious to complete the task (Bargh & Chartrand, 1999; Baumeister & Vohs, 2003). Complex decisions, which require long uninterrupted periods of conscious reasoning, are also more likely to be shifted to nonconscious decision processes. In addition to the effort required, extended periods of conscious deliberations are more likely to be interrupted by perceptions of unrelated information. Conscious attention to the new information acts to force its continued deliberation to the nonconscious. The extremely limited capacity of conscious reasoning makes a conscious review of all decisions made nonconsciously, with any appropriate corrections made before the implementation of the decision as suggested by Kahneman (2011), quite unlikely. Such reviews of nonconscious decisions, however, would be much more likely of novel decisions or decisions due to the presence of large discontinuous changes in the environment (Velmans, 1991).

Some people have been found to more frequently engage in conscious reasoning about economic decisions (Petty et al., 2009; Cacioppo & Petty, 1982). It could be their preferred style of decision making, or it could be due to their desire to explain which factors caused them to make their decisions. I suspect that many readers of this article share this preference. The overall share of decisions made consciously could be marginally higher due to a more highly developed conscious cognitive capacity, but it would still be severely limited compared with the capacity of the nonconscious. Most people do not share this preference since the desired outcome is the decision, not how they would justify that decision. Needless to say, the greater the importance people place on any given decision, the more likely they will engage in conscious cognitive deliberations.

People will often justify their nonconscious decisions after the fact by offering a plausible causal explanation; reasoning by deductive logic is the natural preference of the conscious mind (Nisbett & Wilson, 1977). Nonconscious reasoning is based on associations and favors an inductive methodology, and its use by the nonconscious mind is unknown to most people. Even when people admit that their decision was simply a hunch, an intuition, or even a guess, they may nonetheless cite some likely causes that could rationally explain their decision. These explanations sometimes describe their inferences about their own "black box" by offering what they believe to be consistent explanations of their decisions. While an accurate explanation of the factors underlying decisions are critical to decision theorists, the dominating goal of people is to efficiently use their full mental faculties to make an enormous number of decisions.

Pre-conscious, conscious, and nonconscious

The choice of conscious and nonconscious information processing is typically made at a preconscious stage. If it were made as a conscious choice, that decision would needlessly deplete people's limited conscious resources. Moreover, it is unreasonable to assume that people would consciously decide to make a decision nonconsciously. The actions of the preconscious do not emanate from the pre-frontal cortex, but from the much older limbic system whose functions include coordinating sensory information and relaying the information to other parts of the brain (Curtin, 2019). The preconscious sorting is based on people's goals and motivations as well as the occurrence of new or unexpected events. Even if the decision was initially based on conscious reasoning, people may still voice a desire to enter the nonconscious state of sleep before the decision is finalized. Sleep is known to integrate conscious and nonconscious processes, providing greater confidence or uncertainty about the proposed decision (Fischer et al., 2006; Wagner et al., 2004).

Driving a vehicle is a good example of how the preconscious guides decisions to create a seamless interplay of conscious and nonconscious cognitive decision processes. One might expect that driving is always accompanied by conscious attention, but it is not. Imagine your daily commute to work along familiar routes. If the drive is uneventful, most decisions will be made nonconsciously. Stopping at traffic lights and making the correct turns are under the automatic control of the nonconscious. Most of people's conscious thoughts are instead focused on the latest news on the radio, enjoying music, or engaged in a conversation with a passenger. If asked after you arrive at work whether the traffic light at particular intersection was green or red, most likely you could not recall with any degree of certainty. You automatically entrusted your nonconscious reasoning ability to get you safely to work. The same would be true if you walked or used your bike to get to work.

What if on your trip to work you suddenly saw a dog dart into the roadway, or erratic driving by another vehicle? Conscious control of your driving occurs promptly and automatically. Indeed, in the milliseconds before conscious awareness of the danger, your foot has automatically begun to break the vehicle or your arm has begun to steer your vehicle away from danger. Shifting from nonconscious to conscious awareness occurs more frequently in reaction to non-threatening situations, such as noticing a colleague also driving to work, or a friend heading to the coffee shop, and so forth. After arriving at the office, you can vividly remember avoiding the dog or the erratic driver, or some more pleasant recollections of colleagues and friends.

Those experiences would differ if you needed to drive to an unfamiliar location. Conscious awareness would be heightened, conscious attention would be given to street names and intersections, and perhaps you would ask a fellow passenger to keep watch for where you needed to turn. Some people also want to decrease distractions to consciousness by turning the radio off. If the trip required driving on a freeway for a distance, most people would automatically shift their driving to nonconscious decisions until they approached the appropriate exit.

The situation would be much different for new drivers. Conscious attention would be required until they had gained sufficient experience. Young drivers need to reduce distractions, including radios, texting, and even being accompanied by other young passengers. Nonconscious driving decisions accumulate slowly over time based on conscious decisions. New drivers cannot learn simply from books but need actual experience to build their nonconscious decision capacity. The same is true for any number of skills, such as playing a sport or a musical instrument.

Consider another example, that of grocery shopping. The goal of most shoppers is to get the provisions they need within their budgets. Most shoppers do not consciously review the price of every product they select as it would greatly expand the required time to accomplish the task. While most prices are processed nonconsciously, an unusually large price change is likely to cause a conscious decision: a large price increase may cause shoppers to choose another brand, substitute another product, or simply eliminate the purchase; a large price decline may cause shoppers to purchase an additional amount if they thought it was a temporary price decline.

The essential point of the driving and shopping examples is that there is a seamless integration of conscious and nonconscious information processing and cognitive reasoning. The mutual assistance is independent of the risks involved, even life-and-death decisions, but is dependent on building cognitive competencies based on experience. Cognitive reasoning is no less capable when guided by the nonconscious than the conscious. The same degree of accuracy as well as biases are shared by the cognitive resources, whether conscious or nonconscious.

Nonconscious learning

How do people learn to make decisions nonconsciously that serve their best interests? Most scientists consider conscious reasoning to be based on a deductive methodology and causal models. These methods and models are reputed to yield the most reliable and accurate decisions. Importantly, such decisions can be examined to identify any misleading assumptions, misidentified models, or mismeasured predictors in order to improve the accuracy of the resulting decisions. In contrast, scientists have generally found the use of inductive methodology and modeling by associations to generate results that are more unreliable and less accurate. Importantly, this preference for deductive methodology is shared by most people, since when asked to explain their decisions they naturally use the language of deductive models and causal reasoning; this is true even when people had already said that their decision was based on intuition, a hunch, or even a guess. Nonetheless there are several advantages to basing decisions on associations and inductive logic.

The appeal of focusing on associations is that inferences do not depend on an existing theory. No prior theory is required by the nonconscious. Associations are naturally formed as perceptions of events are processed nonconsciously. Nonconscious observations are not static, but are dynamically modified with repeated processing of similar data. Interrelationships across observations emerge, including contingent associations, reflecting the natural complexities of relationships among variables. Nonconscious cognitive resources do not use a theoretical framework to catagorize variables, nor does it produce causal models. Predictions are based purely on associations. Given the vast capacity of the nonconscious, people process immense amounts of data on every facet of their environment.

How does nonconscious learning occur? It begins with nonconscious awareness and processing of frequencies of certain events, accomplished without conscious knowledge. The nonconscious becomes sensitive to regularities in the observations and its associations with other observations. This process is not consciously accessible and cannot be verbally reported. This process has been called implicit learning or tacit knowledge (Reber, 1967; Lewicki, 1986). In population language, it is call intuition, instinct, or a gut feeling. People also readily admit that they are unaware of the underlying reasons for these views, but they have learned by experience that their instincts serve as a good guide for their behavior. Implicit learning can provide more general insights to evaluate a potential decision as well as quite specific decision guidelines.

Milton Friedman's expert billiard players rely on their implicit knowledge, without any explicit knowledge of the physics involved, to make the most difficult shots. The billiard player can demonstrate the most complex aspects of the underlying theory effortlessly and more quickly than by calculating the optimum trajectory of the ball, its speed, and spin. Players accomplished this task by the slow nonconscious accumulation of experiences that gradually modified and sharpened their skills. The nonconscious is capable of processing multidimensional and interactive relations between variables. Importantly, this skill does not depend on age. From a very early age, infants have the capacity to nonconsciously learn associations and infer structural properties among events.

It is a surprising result to many that the use of associations and inductive methodology can match the results from the use of causal models and deductive methodology. It could be argued that inductive methodologies cannot yield the precision to extended decimal points that is a standard feature of causal models. Implicit knowledge has the advantage that it is effortless and its unmatched speed would mean that conscious deliberation and decision making would be unable to match. Whereas scientific inquiry puts its entire emphasis on accuracy, people's reasoning ability has the dual goals of efficient and accurate decisions. It should be no surprise that more timely decisions maximize utility even if the decision accuracy could be improved by devoting more time to the decision; satisficing rather than decimal-point accuracy has long been recognized as a common objective. Satisficing is not irrational when prompt decisions are critical to people's welfare, or the failure to make a timely decision involves substantial future losses.

From an evolutionary perspective, it is hardly surprising that associative learning has been shown to approximate optimal solutions (Rescorla & Wagner, 1972). Most tasks require a harmonious relationship between implicit and explicit knowledge. Sleep promotes learning as it enhances implicit and explicit relationships through consolidation of learning. Notably, some types of implicit knowledge can become explicit during sleep and available to conscious thought (Fischer et al., 2006; Wagner et al., 2004).

The oldest and most replicated study of nonconscious learning is artificial grammar (Reber, 1967 for a review). The experimental protocol exposed subjects to nonsensical strings of letters. After some practice viewing the strings, subjects were told that the strings were formed according to a set of rules. Subjects were then asked to generate valid strings or asked to determine whether some strings were validly formed. The subjects performed these tasks significantly better than chance, but were unable to verbalize the underlying rules. These results have been widely interpreted to indicate an implicit knowledge of the underlying rules occurred independently of conscious effort or awareness. Furthermore, such nonconscious knowledge was retained over long periods of time, even after two years in one study (Allen & Reber 1980). Another long standing and replicated experiment found that subjects could nonconsciously detect covariations across events and objects (Lewicki, 1986 for a review).

Another set of experiments that are perhaps more relevant to a study of economic behavior focuses on the management of a "sugar factory." The factory and its operations were in the form of a computer game. The goal of the subjects was to control various inputs to a "black box" production function to maximize profits (Berry & Broadbent, 1988). Subjects learned to control production by repeatedly adjusting the number of employees and amounts of other inputs as well as adjusting the lagged impact of these inputs on production and profits. Subjects were never told the underlying rules that generated maximum profits, but with adequate practice they performed at much better than chance levels. Even the subjects who fully mastered the game were unable to verbalize the full set of underlying rules, although they could identify the manipulations that they had used. In another experiment, each subject was told the rules that generated production and profits before they started managing the sugar factory. Conscious knowledge of the rules did not quickly enhance their performance; it actually took more time for the subjects to learn how to best control production (Reber et al., 1980; Sterman, 1989). The results of these experiments underscore the speed and accuracy of nonconscious learning. Gigerenzer's (1996) description could be revised to "fast, frugal, and reasonably accurate," to summarize the nonconscious speed advantage, lower mental cost, and its accuracy.

Another experiment confirmed that simultaneous attention to different events by the conscious and nonconscious. This was demonstrated by experiments in which subjects were shown sixty ads on computer screens, along with seventy-five changes in the prices of five stocks (Betsch et al., 2001). Subjects were told the purpose was to test their recall of information presented in the ads, and that the information on stocks was simply meant as a distraction. Following the ad recall tests, subjects could correctly rank order the performance of the five stocks, but could not accurately recall the detailed information on prices. The experiment showed both the simultaneous processing of information, and the lack of conscious knowledge of the details of the nonconscious process.

Parallel developments in econometrics

Most scientists have judged that nonconscious learning based on observed associations as destined to yield biased and unreliable results. A common lesson taught to every schoolchild is that "correlation does not imply causation," and this belief has been the defining characteristic of scientific research. Although the scientific adherence to causal modeling is not in jeopardy, model building is likely to take advantage of the same inductive methodologies used by the nonconscious. One reason involves the vast quantities of data now routinely generated in the digital era, and the other, perhaps more important reason, involves the inherent instabilities in the econometric specifications of empirical models and relationships.

Behavioral economists have always demanded extensive data on every aspect of each person's economic circumstances. "Big data" now provides nearly instantaneous details on almost every economic transaction. The critical difference is that the analysis of big data depends on drawing inferences from associations, and theory building based on an inductive methodology. Big data advocates hold that as long as prediction is the ultimate judge, the lack of causal models will not be a significant disadvantage. Indeed, econometricians who have had unquestioned faith in causal models, have recently come to the same conclusion for quite different reasons. Factor models that are explicitly based on observed associations represent the latest innovation in econometric forecasting. The power of this new technique is due to the elimination of errors in the identifying restrictions used to estimate standard econometric models (Sims, 1980), and due to the instability of the structural models (Hendry & Krolzig, 2005). The general conclusion is that the true model is best conceptualized as relationships among unobserved variables. Thus, people's nonconscious learning as well as econometricians both rely on observed covariances to draw conclusions. Only the outcomes of decisions can be recalled from nonconscious learning, that same limitation partially affects econometricians' explanations of their predictions.

Inherent numerical sense

Most economic decisions involve numbers. Does knowledge of numbers limit economic decisions to conscious rather than unconscious processes? The complete answer is that it depends on the type of calculations involved. Most observers, however, are surprised by how much the nonconscious can accomplish. It has been long known that people possess a basic knowledge of numbers, which develops soon after birth. Arabic numerals as well as the word representations of numbers can be processed nonconsciously and automatically as quantities (Dehaene & Akhavein 1995). These numerical abilities are universal, spanning all cultures, and are even present in the most isolated societies. This numerical capacity represents our common evolutionary history.

People actually have two mental number systems, one for small numbers and another for large numbers (Feigenson, Dehaene, and Spelke, 2004). The first is for the precise representation of a small set of cardinal numbers, 0 to 3. People know these numbers intuitively and use them with precision. Larger quantities quickly exceed the processing capacity of this innate system. The second system is for large numbers, called the "mental number line." This second system represents the meaning of large numbers as approximate magnitudes (Dehaene, 1997, 2003). Rather than the exact precision, people assess differences in quantities based on the "just noticeable difference." This quantity is proportionate to the magnitude of the numbers. This is sometimes referred to as Weber's Law, which holds that as quantities increase, their meaning is interpreted logarithmically. The eye senses brightness approximately logarithmically, the ear senses loudness by the logarithmic scale of decibels, and the magnitude of earthquakes are judged by the logarithmic Richter scale. The same logarithmic characteristics applies to the mental number line. As a result, the capacity to accurately distinguish between two very large numbers is limited, and becomes more limited as the quantities increase.

The implications of the mental number line for economic decisions are obvious. Few people can cite the current size of the Gross National Product in trillions of dollars, or can readily assess the meaning of the absolute change from last quarter. Meaning derives from a logarithmic transformation of the data (Izard & Dehaene, 2008). Most people can differentiate between a 5% and a 10% change, which simply represents the differences in the logarithms. Mental number lines thus provide people with the ability to determine what constitutes "reasonable" accuracy: it is the smallest relative amount they usually perceive – or what could be called satisficing. Economists follow the same procedure when using data to judge trends in GDP and its components: percentage figures are used to interpret, analyze, and understand the data. For economists these procedures essentially represent conscious cognitive reasoning, whereas all people (including economists) can use a comparable process of nonconscious reasoning to reach similar conclusions. The key difference is that the explicit calculations are more effortful and far more costly.

Preference for frequencies

There are some critical limitations to people's innate numerical capacity. Negative numbers, fractions, square roots, and a host of other mathematical operations are outside the domain of the nonconscious mental numbers. These elements must be explicitly learned, require a basic understanding of mathematics, and are dependent on the development of logical skills; all of these numerical manipulations must be accomplished consciously. In contrast, the nonconscious uses an inductive methodology, based on accumulating natural frequencies and making associations across observations. The probability or percentage of times an event occurs is not stored in memory or used by the nonconscious, rather it is the frequency with which a particular event has happened (Gigerenzer, 1998). Although this information allows the calculation of a probability, the opposite in not true as no frequency can be calculated from probability data. The nonconscious mind's sole focus on frequencies is a matter of efficiency as frequencies represent the most generalizable data.

Behavioral economists favor probabilities over frequencies, which allows analysts to take advantage of Bayes' powerful theorem on conditional probabilities for prediction purposes as well as to update earlier predictions based on the latest available information. While Bayes' theorem was published following his death in 1761, people had no regular exposure to probabilities until the second half of the 20th century (Gigerenzer et. al., 1989). Probabilities require effortful conscious reasoning, while people can process frequencies automatically and nonconsciously (Hasher & Zacks, 1984). Evolution has developed people's abilities to make statistical judgements based on natural frequencies (Brase, Cosmides, and Tooby, 1998).

Frequencies are thus the privileged representational format. Natural frequencies have been shown to foster statistical insight and allow people to become "intuitive statisticians (Cosmides & Tooby, 1996; Gigerenzer & Hoffrage, 1999; Nisbett et al., 1983). These innate abilities do not diminish with age. In comparison with conscious cognitive skills that increase in childhood and decline in old age, nonconscious processing abilities remain largely unchanged over the entire life span (Midford & Kirsner, 2005). Moreover, the capabilities of nonconscious processes are more equal across the population due their evolution over millions of years in comparison to the about two-hundred thousand years for conscious processes.

Conscious and nonconscious rationality

Definitions of rationality have never included a reference to whether conscious or nonconscious cognitive reasoning was used; nonconscious processes were more likely to be simply ignored. The intent of this article has been to provide convincing evidence that most economic decisions represent a complex intermingling of conscious and nonconscious cognitive reasoning. Both are capable of processing data, determining relationships, learning the underlying structure of those interrelationships, and both are capable of making rational decisions. The nonconscious possesses some crucial advantages since its relative capacity for cognitive deliberation is immense, and given its ability to devote long spans of uninterrupted time to cognitive possessing and learning. People repeatedly shift the mental locus of control depending on the requirements of their simultaneous pursuit of several tasks and multiple goals. There is no longer any justification to ignore the important role played by nonconscious cognitive reasoning.

How is decision rationality determined? People are assumed to engage in a maximization process to optimize the efficiency and accuracy of their own mental faculties. Who could object to people using the most efficient and least costly reasoning ability, including the processing of information, learning from its associations, and implementing and guiding behavioral decisions? Given that the goal is to maximize overall utility, rationality is not judged by isolating the contributions of its separable components, but utility is judged by the combination of all its components. Some components may not be optimal, but there drain on overall utility may be more than offset by the contributions of other components. The two key constraints typically unrecognized are the high opportunity costs of conscious deliberation and the need to make an enormous number of decisions in a timely manner. Expanding the time needed to make decisions consciously must be balanced against losses due to foregone decisions.

There is no questions that people's most valuable mental resource is their ability to make conscious deliberative decisions. This resource has demonstrated its unique ability to generate a wide and growing array of scientific and artistic achievements. People's nonconscious reasoning resources uses a different methodology designed to collect and analyze data by associations, without the benefits – or drawbacks – of causal models and deductive logic. The nonconscious is ideally designed for exploratory analysis, operating in a manner that is just as productive in the 21st century as in past centuries when quite different theories dominated conscious reasoning – many of which have long been abandoned. The advancement of behavioral economics requires a more inclusive view of how people use their combined reasoning faculties.

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