standards, very expensive calculations. Computing the properties of a collection of 540 transition metal atoms is made possible only through the development of extremely efficient algorithms and very fast computers. These large calculations are necessary because the geometry of the dislocation couples with the chemistry to produce the final results. Similar calculations in the absence of the dislocation fail to produce the experimentally observed trends [see table S1 in the supporting online material (*1*)]. The quantum mechanical predictions are then incorporated into the kink nucleation rate, and yield the potential for solute-induced softening.

With the fundamentals of softening understood, Trinkle and Woodward need to account for the solute-induced strengthening effects observed at higher solute concentrations. In doing so, they rely on functional forms rooted in elasticity theory, an analysis of the statistics of pinning, and the direct computation of solute/dislocation interaction energies (again rooted firmly in quantum mechanics). The net result is a quantitative prediction of the softening/strengthening properties of solutes in molybdenum.

Trinkle and Woodward's research is appealing beyond the simple fact that they have solved one of the outstanding puzzles of metallurgy. Their study represents a remarkable application of three types of theories (quantum mechanics, statistical methods, and continuum dislocation theory) and a remarkable tool (a fast computer) to solve this metallurgical problem. The field of computational materials science has promised to aid in the design of structural materials for specific purposes. Though there is much more work to be done, Trinkle and Woodward have taken a small step toward this elusive goal. Their detailed theory of the interaction of solutes and dislocations provides a framework that a metallurgist can employ to improve materials properties. In doing so, they have provided an inkling into the practice of metallurgy in the age of silicon.

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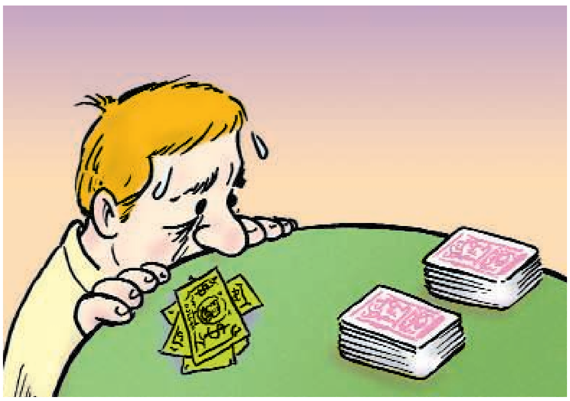
NEUROSCIENCE

Emotion and Reason in Making Decisions

Aldo Rustichini



Decisions, decisions. Our brain treats choices involving risk or ambiguity differently.

Two decks of 100 cards each are on a table. The one on the right has 50 red and 50 blue cards; the one on the left also has red and blue cards, but I don't tell you how many of each. You pick one card from each of the two decks, without looking at the color. Now you can bet on the color of a card of your choosing between the two, and I will give you $100 if you guess right. Do you bet on the right or the left card? You may be inclined to choose the right. Before you answer, note that sheer logic dictates that you should consider the left one as just as good a bet too. Here is why. Choose the left deck, and flip a coin to choose a color. If the card is red, you will match the color with 50% probability. If it is blue, the same conclusion holds. Therefore, no matter what the color of the left card, you have a 50-50 chance of winning $100, which is also what the card on the right side will give you. Are you convinced? If not, are you willing to give me an extra dollar to get your preferred choice?

Although the logic is impeccable, most people are not convinced and prefer to bet on the right deck because "they know the probability." They are also willing to pay to avoid the vagueness plaguing the left deck. If asked to pay, people offer around $42 for the left deck and $45 for the right deck. The right deck's average worth is $50; the $5 difference between the offer for the right deck and its average worth is what economists call the risk premium, a way to measure aversion to risk. The additional $3 difference between the prices offered for the two decks is the ambiguity premium, a measure of aversion to the vagueness of the probability. In real life, the ambiguity premium may be substantial. For instance, it is a large part of the difference between the higher price of stocks of domestic companies, as opposed to cheaper foreign ones: People like better what they know.

Economists in recent decades have realized [since (*1*)] that people are averse to ambiguity. To account for this behavior, they (*2*) have built and used a formal decision theoretic model. It formulates the idea that when the probability is not precise, people are inclined to consider the worst possible outcome of each action they can take as the outcome that will occur. In our example, if you choose the ambiguous card deck, the worst possible outcome for each color you choose is $0. You are facing a malevolent opponent who can choose the outcome that is least favorable to you.

This is now an accepted and widely applied model (*3*–*6*). But is this just a clever mathematical model, or does it correspond to a real process in the brain? This formal theoretic model of ambiguity aversion has two main predictions. The first is that subjects approach a decision with ambiguous probabilities in the same way as they do when they face a malevolent opponent. The second is that they deal with this situation as a calculated risk: In choosing with ambiguous probabilities, subjects estimate the worst case, how likely it is, and how much it pays. Dealing with decisions facing ambiguity is a process involving both emotion and reason. Is this what we observe?

On page 1680 of this issue, Hsu and colleagues (*7*) report on a functional magnetic resonance imaging study that may give us physiological clues as to the nature of ambiguity. The main result is that the brain treats the two card decks in the example above in different ways. Distinct areas of the brain are active when we evaluate ambiguous and risky choices. Moreover,

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patients with large lesions that incorporate one of these areas (the orbitofrontal cortex) treat ambiguous and risky choices differently from normal subjects.

Twenty-four different areas in the brain are more active under conditions of ambiguity than risk. Among these regions, Hsu *et al*. focused on those that previous researchers have, with some controversy, associated with the emotional side of decision-making. However, a large number of these areas (located in the temporal, parietal, and prefrontal lobes of the brain) deal with the estimation of the values of the options, which suggests that the decision process integrates emotional and computational components. The results confirm earlier findings that not only are ambiguity and risk treated differently by the brain (*8*), but so are related situations such as when one considers sure and risky outcomes, or monetary gains and losses (*9*). Taken together, these findings support the theory of ambiguity aversion that economists have described.

What is next? Elucidating the neural processes underlying decision-making may help us understand important economic differences between ambiguity and risk. Human attitude to risk fuels the substantial profits of two large business sectors of our economy—gambling and insurance. In contrast, there is no sector served specifically by our aversion to ambiguity. This difference between risk and ambiguity is related to an experimental fact: If I ask you to choose repeatedly among risky options, your risk premium remains stable. But recent experimental evidence (*10*) suggests that the ambiguity premium declines as subjects repeat their choices: People slowly adjust to ambiguity; they do not adjust to risk. Just as we learn to act optimally given the actions of others (the Nash equilibrium of game theory), by choosing repeatedly, one may be learning, slowly, to deal with ambiguity in our choices.

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ATMOSPHERIC SCIENCE

Land Use and Climate Change

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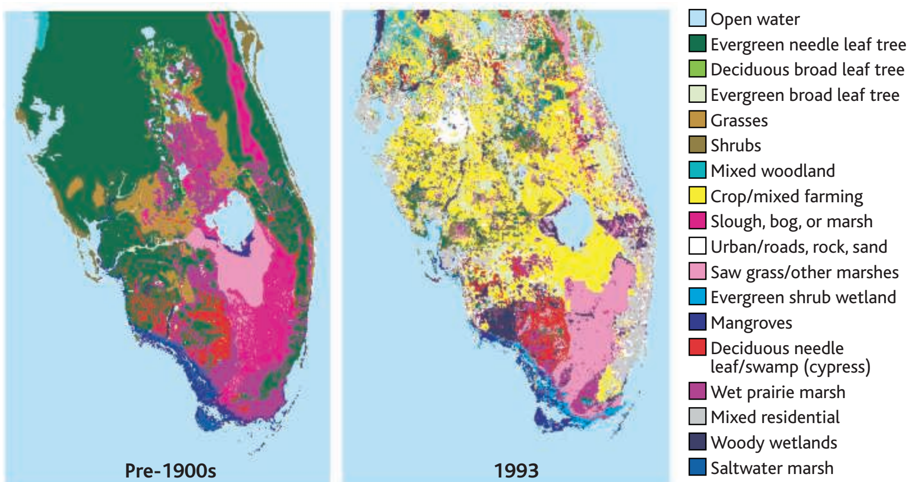
Change and variability in land use by humans and the resulting alterations in surface features are major but poorly recognized drivers of long-term global climate patterns (*1*, *2*). Along with the diverse influences of aerosols on climate (*1*, *3*, *4*), these spatially heterogeneous land use effects may be at least as important in altering the weather as changes in climate patterns associated with greenhouse gases. On page 1674 of this issue, Feddema *et al*. report modeling results indicating that future land use and land cover will continue to be an important influence on climate for the next century (*5*). One implication of this work is that the Intergovernmental Panel on Climate Change (IPCC), which has yet to appreciate the significance of the full range of phenomena that drive climate change, risks rapidly falling behind the evolving science if this effect is not included. Although the impact of land use and land cover on the atmospheric concentration of carbon dioxide and methane, and on the global average surface albedo, have been included in international climate change assessments (*6*), the role of land use and land cover change and variability in altering regional temperatures, precipitation, vegetation, and other climate variables has been mostly ignored.

The importance of land use and land cover change and variability should not be a surprise. On the basis of research by Avissar and co-workers at Duke University, NASA reports that "scientists estimate that between one-third and one-half of our planet's land surfaces have been transformed by human development" (*7*). A large body of research has documented the major role of land use and land cover change and variability in the climate system (*8*–*12*).

One example of how land use and land cover affects global climate is the changing spatial and temporal pattern of thunderstorms. Land use and land cover change and variability modify the surface fluxes of heat and water vapor. This alteration in the fluxes affects the atmospheric boundary layer, and hence the energy available for thunderstorms. As shown in the pioneering work of Riehl and Malkus (*13*) and Riehl and Simpson (*14*), at any time there are 1500 to 5000 thunderstorms globally (referred to as "hot towers") that transport heat, moisture, and wind energy to higher latitudes. Because thunderstorms occur over a relatively small percentage of Earth's surface, a change in their spatial patterns would be expected to have global climate consequences. The changes in the spatial patterning of thunderstorms result in regional alterations in tropospheric heating that directly change atmospheric and ocean circulation patterns, including the movement and intensity of large-scale high- and



Changing surface patterns. Vegetation classification of the Florida peninsula before 1900 (**left**) and in the 1990s (**right**), which shows the dramatic conversion of the region's landscape during the 20th century. [Reprinted from (*21*) with permission]

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