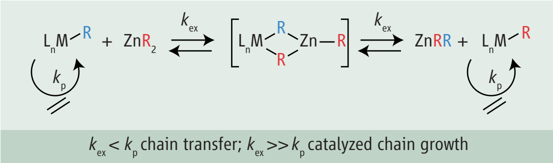
metal center to a dormant main-group metal species has been known since the early days of polyolefin catalysis. Its origin can be traced back to Karl Ziegler (*7*), who, in the early 1950s, discovered that a mixture of $TiCl_4$ and trialkylaluminums could catalyze the formation of polyethylene (hence founding metal-catalyzed polyolefin production). Ziegler postulated that the transition metal could be acting as a catalyst for the insertion of ethylene into the Al–C bond, a reaction which he termed a metal-catalyzed Aufbau reaction.



Chain shuttling. Reversible alkyl-group exchange between dormant zinc and polymerization-active transition-metal centers can be used to tune the properties of the resulting polymers.

Ziegler soon realized that the titanium centers were responsible for catalyzing C–C bond formation, whereas the function of the Al species was to deliver an alkyl-initiating group to the transition metal. However, analyses of polyethylene samples generated by a variety of catalysts have revealed that aluminum alkyls readily engage in an exchange reaction with their transition-metal catalyst partners (*6*). Some have been found to do this very efficiently, to the extent that chain transfer to aluminum is actually faster than ethylene insertion into a metal-carbon bond. This regime, known as catalyzed chain growth (*8*) or degenerative group transfer (see the second figure), leads to chains with a remarkably narrow (< 1.1) and symmetrical distribution of chain lengths. The narrow molecular weight distributions can be used as an indicator of suitable chain-transfer behavior for the chain shuttling reaction.

Other main-group alkyls, including those of Mg (*9*), and more recently Zn (*5*, *10*, *11*), have also been shown to facilitate highly efficient chain transfer to and from transition-metal centers. Zn is among the most efficient chain-transfer reagents for single-site catalysts across the transition series, because the metal-carbon bond energies of the zinc alkyl closely match those of transition-metal alkyl species, the polarities of the Zn–C and M–C bonds are similar, and the mononuclear dicoordinated Zn centers are uncrowded.

To form microblock materials, two catalysts are used within a common pool of chain-transfer reagent (*3*); propagation must be faster than chain transfer to the main-group metal center, and the relative rates of chain transfer will dictate the average block lengths. Because the degree of chain transfer is affected by several factors—including the concentration of chain-transfer reagent, the concentration of monomer, and the temperature of the polymerization—it should be possible to find a set of conditions to allow the formation of the desired microblock structures.

However, the identification of catalysts that yield differentiated microstructures at appropriate rates of chain transfer presented a substantial challenge. By combining advances in single-site polymerization catalysis with powerful high-throughput screening methodologies, Arriola *et al.* have been able to home in on catalysts that enable both microstructural control and efficient chain shuttling. Moreover, they show that the catalysts can be used in a continuous process, which has the advantageous effect (from a polymer processing viewpoint) of broadening the molecular weight distribution; a broad molecular weight distribution allows the polymer to be extruded (pushed) through a narrow aperture. The shorter chains present in the broad distribution effectively lubricate the material.

Arriola *et al.* elegantly demonstrate the advantages of combining two catalysts and a single type of monomer with a shuttle reagent, but the plethora of materials that might prove accessible by using multiple catalysts and monomers can only be imagined at this point. Combining catalysts would add many additional and attractive possibilities. Because the polymer chains end up attached to a main-group species, the intrinsic reactivity of the main-group alkyl may potentially be harnessed to access end-functionalized products. For example, Zn alkyls react readily with gases such as oxygen to give Zn alkoxides, which can then be hydrolyzed to alcohols, or with CO_2 to form carboxylic acids; these may have applications as surfactants (for low–molecular-weight products) or as functionalized polyolefins with enhanced surface energies. This catalyst shuttle technology provides the long-sought platform for producing microblock polyolefin materials on a commercial scale.

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SOCIAL SCIENCE

The Pleasures and Pains of Information

George Loewenstein

Information serves not only as an input into decision-making, but is a source of pleasure and pain in its own right. This has diverse consequences for human decision-making.

In 1961, economist and Nobel Laureate George Stigler (*1*) initiated the "economics of information" when he relaxed an assumption that had dominated economics until that point. Rather than assume that people are fully knowledgeable of relevant information when it comes to making a decision, he allowed for the possibility that people might lack information and be motivated to acquire it. As Stigler noted when he accepted the 1982 Nobel Prize, "The proposal to study the economics of information was promptly and widely accepted, and without even a respectable minimum of controversy. Within a decade and a half, the literature had become so extensive and the theorists working in the field so prominent, that the subject was given a separate classification in the *Index of Economic Articles*." Stigler acknowledged that "The absence of controversy certainly was no tribute to the definitiveness of my exposition." Rather, "All I had done was to open a door to a room that contained many fascinating and important problems" (*2*).

Relaxing the assumption of perfect information did, indeed, open new doors for econo-

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mists. Yet the economics of information that emerged from Stigler's seminal contribution embraced its own set of strong assumptions about how people deal with the information they acquire. Although these assumptions have proven their value, forming the basis for tractable models that generate testable, often valid, predictions of decision-making and market outcomes, several of the new assumptions are as patently unrealistic as the original assumption of perfect information. Much as the allowance for imperfect information initiated a rich vein of new work, relaxing some of the assumptions that took its place has the potential to help resolve important puzzles for economics. These include inconsistencies in the apparent degree to which people take account of the future, and the human tendency to avoid information in certain situations or fail to draw seemingly obvious conclusions from the information one receives.

One tenet of the economics of information that may be ripe for modification is the assumption that information is not valued in its own right, but only insofar as it informs decision making and enables decision-makers to secure desired outcomes. On page 754 in this issue, Berns *et al*. (*3*) challenge this assumption by showing that people not only dislike experiencing unpleasant outcomes, but also dislike waiting for them. Confronting human subjects with the prospect of an impending electric shock, the authors find that regions of the pain matrix (a cluster of brain regions that are activated during the experience of pain) are also activated in anticipation of shock. This activation intensifies as the shock becomes imminent. The information that one is going to receive an electric shock, like the shock itself, is a source of misery.

The idea that people derive pleasure and pain directly from information, rather than from any material benefits that the information procures, has diverse implications for decision-making. As highlighted by Berns *et al*., utility derived from anticipating future outcomes can have a major impact on intertemporal choices—decisions involving costs and benefits that extend over time. The standard economic account of intertemporal choice predicts that people will generally want to expedite pleasant outcomes and delay unpleasant ones (*4*). If, however, people derive pleasure or pain from the information that an outcome will occur in the future, they may prefer to defer desired outcomes so as to prolong the pleasure of anticipation or to expedite unpleasant outcomes so as to shorten the period of dread. In the Berns *et al*. study, 84% of subjects preferred to get electric shocks over with quickly. Ignoring the utility of information, the standard account would predict instead that subjects would prefer to defer the shocks.

Earlier studies posited a causal link between anticipatory utility and the desire to get unpleasant outcomes over with quickly (*5*). However, Berns *et al*. actually observe a correlate of dread in the brain activity of human subjects and a significant relationship between individual differences in this measure and individual differences in intertemporal choice behavior (*6*). In tandem with other recent work that highlights the role of emotions in intertemporal choice (*7*), and consistent with historical accounts of intertemporal choice behavior (*8*), these findings support the idea that the decision to delay or expedite an outcome depends critically on how a person feels while waiting. When waiting is pleasurable, people will often prefer to defer. When it is unpleasant, however, because waiting for an unpleasant outcome produces dread or waiting for a pleasant outcome generates frustration, people will prefer to expedite outcomes—even, sometimes, at the cost of experiencing worse ones.

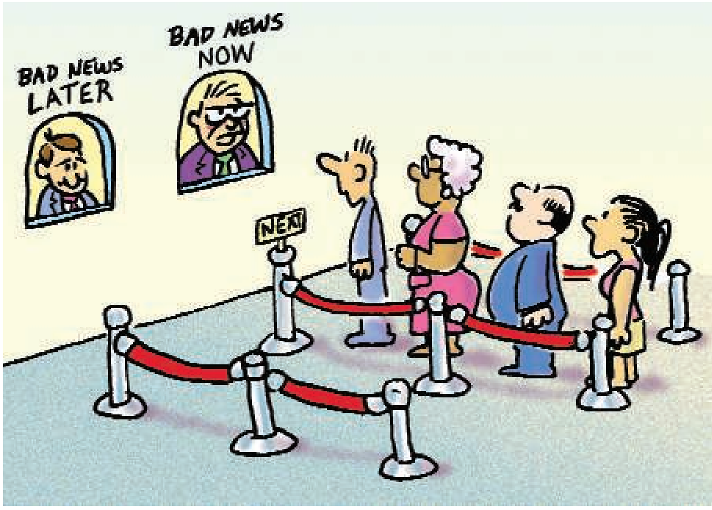
The idea that people derive utility directly from information has a variety of consequences that go well beyond the domain of intertemporal choice. Emotions, such as fear and excitement, can dramatically change people's willingness to take risks (*9–11*). And utility derived from self-image—that is, from information about one's value as a person—can have diverse ramifications, including encouraging prosocial behavior (*12*, *13*).

Utility from information can also affect the demand for information. Conventional economics predicts that people should prefer more information to less. If people derive utility directly from information, however, they may sometimes be motivated to avoid information, even if it is free and useful for decision-making (*14*). Indeed, people often avoid getting tested for medical conditions because they are afraid of getting bad news (*15*), and investors are more likely to look up the value of their portfolios when the stock market is up (and the news about one's own portfolio promises to be favorable) than when the market is down (*16*).

Beyond sometimes motivating the avoidance of information, the utility associated with information also provides people with an incentive to process information in a biased fashion—to form "motivated" beliefs that feel good in the short run but can distort decision-making (*17*). People are remarkably adept at finding reasons to believe what they wish were true and not believe what they wish were not true (*18*). For example, someone who is worried about the health of a loved one is often the last to view the situation in objective terms. Instead, he or she grasps at remedies—however far-fetched—that promise hope. Or consider the many people who fall prey to pyramid and Ponzi financial investment schemes. Although economists argue that there is no such thing as a free lunch, this behavior suggests that many people are quite willing to be persuaded otherwise.

These examples just scratch the surface of promising directions for research on the utility of information. For example, neither economists nor psychologists have advanced a theory that can explain when and why waiting for a desired outcome is pleasurable or, instead, frustrating, even though the emotional response to anticipation may be the single most important determinant of people's willingness to delay gratification. As another example, theories of investor behavior assume unrealistically that paper gains and losses (changes in the value of owned assets) provide the same utility as realized gains and losses (those that result from actually selling assets). Relaxing this assumption may help to explain a wide range of perplexing investor behaviors, such as the tendency to hold on to losing stocks (by holding such stocks, investors limit themselves to paper losses as opposed to actual losses). We also lack a convincing theory to account for and predict the market bubbles and busts that wreak havoc on economies. Such a theory will almost inevitably incorporate interactions between expectations and emotions such as the paradigmatic "fear and greed."

As the first of its kind, the study by Berns *et al*.



Bring it on. People generally choose to get unpleasant things over with quickly.

CREDIT: JOE SUTLIFF

has limitations. Given the constraints of brain imaging, for example, the time intervals over which the study's subjects make decisions (about 30 s) are shorter than the decision intervals of greatest interest to economics. Moreover, the authors observed the connection between dread and intertemporal choice across subjects in two separate tasks. It would provide stronger evidence that dread is playing a causal role if activation in a single task was correlated with decisions made in the same task. The authors assume, finally, that dread is better represented by the summed total of anticipatory activation over the duration of the waiting period. But it might make more sense to represent dread as the level of activation at a particular time. These are, obviously, minor limitations given the novelty and importance of the research.

The Berns *et al*. study is a superb new addition to the nascent field of neuroeconomics (*19*, *20*). It also contributes to a new wave of research in behavioral economics that, following Stigler's lead, examines the consequences of relaxing economists' stylized assumptions about how people deal with information (*21*). Both of these new lines of research have generated more controversy than Stigler's initial insight, but will likely prove similarly rich in yielding theoretical results.

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PLANETARY SCIENCE

The Primordial Porridge

Bernard Marty

Interplanetary dust particles contain organic matter thought to have formed either before our solar system or early in its history. Similar matter appears in the oldest meteorites.

The solar system formed from the collapse of a cloud of gas and dust called the solar nebula, through a series of energetic events that have left few traces. Studies of planetary bodies including meteorites have demonstrated that matter was efficiently mixed at an atomic scale before solids were formed. The isotopic compositions of some of the light elements such as hydrogen and nitrogen, however, vary dramatically across the solar system. Mass balance considerations indicate that these isotope heterogeneities are not inherited from previous nucleosynthesic processes in stars. Instead, these isotope variations are likely to have formed in the solar nebula or in interstellar space. Until now, the largest hydrogen and nitrogen isotopic variations have been found in interplanetary dust particles (IDPs), which are micrometer-sized particles flowing in interplanetary space that have been collected in the high atmosphere by NASA stratospheric planes. IDPs have deuterium (D) and nitrogen isotope anomalies found in organic matter, which suggests that IDPs are among the most primitive type of matter in the solar system and could be, in some cases, cometary in origin (*1*). Carbonaceous chondrites, which are volatile-rich meteorites originating from planetary bodies that never melted and differentiated, also exhibit enrichments in deuterium and ^{15}N associated with organic matter, but to a much lesser extent (*2*). These differences are in line with the more "primitive" character of IDPs compared with carbonaceous chondrites. Now, observations by Busemann *et al*. reported on page 727 of this issue (*3*) shed a different light on this view.

By using a new imagery technique that allows the spatial distribution of isotope enrichments to be mapped on a micrometer scale, Busemann *et al.* have discovered tiny "hot spots," where D and ^{15}N are highly enriched in the organic matter of several carbonaceous chondrites. Remarkably, these enrichments even exceed those found in IDPs. Busemann *et al*. propose that carbonaceous chondrites, which are thought to originate from the asteroid belt at 2 to 4 AU (astronomical units equal to the Earth-Sun reference distance), and IDPs, some of which are thought to represent cometary material originating at several tens to hundreds of AU, have both sampled a similar reservoir of exotic material (see the figure). They further propose that the host of these components is a particular resistant form of organic matter that has been equally preserved in carbonaceous chondrites and in IDPs, despite secondary processing that often affected the former or their parent bodies. The discovery made by Busemann *et al*. suggests that comets contain material that shares similarities with carbonaceous chondrites, a possibility in line with the occurrence of refractory silicates and calcium-aluminum–rich inclusions in cometary grains recovered by the Stardust mission and presented in March 2006 at the Lunar and Planetary Science Conference in Houston, Texas (*4*). Thus it appears that large-scale turbulence occurred in the nascent solar system that transferred refractory phases from the inner, hot regions toward the outer solar system and, conversely, disseminated matter that was presumably synthesized outside the solar nebula or in its colder regions up to inner solar regions.

How and where did these isotope anomalies develop? Hydrogen and nitrogen isotope hot spots observed by Busemann *et al.* in meteoritic organics do not coincide spatially. On a larger scale, such isotope variations among different solar system objects do not define a single relationship, suggesting that different paths or processes may

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