Anatomy of Give and Take

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HOUSTON — The two women had money in mind.

Phuong Tang, 25, wriggled into a $2.5-million brain scanner at Baylor College of Medicine. Across the hall, a technician loaded Tang's trading partner for the day — Kavita Belur, 26 — into the bore of a similar machine, like a fresh artillery shell.

The two strangers were speculators in a marketplace of the mind, locked in a mutual struggle for financial gain. Belur played an investor, Tang the trustee of an investment fund.

As the pair wavered between cooperation and betrayal, scientists recorded how their brains changed. The researchers hoped to discover the secret of trust — the human variable missing from the mathematics of modern economics.

The terms of the experiment were simple: At the beginning of each round, Belur could put up to $20 in play. Any investment automatically tripled. Tang then decided how much to return and how much to keep.

Belur's safest strategy was to hoard all of her money. Tang's most logical move was to cheat her partner at every opportunity.

There was a riskier but potentially more profitable way.

They could trust each other.

The experiment was part of a new frontier in the exploration of the brain — a field called neuro- economics that seeks to understand the biology underlying economic behavior.

In universities and research centers across the country, scientists are probing the brain with coin flips, $5 bills and gift certificates from Amazon.com. Bit by bit, they are assembling a mosaic of the financial brain, identifying how competing neural circuits shape decisions.

"We have started looking for pieces of economic theory in the brain," said New York University neuroscientist Paul Glimcher.

Researchers believe they can discover how neural networks affect the ways people buy and sell, splurge and save. They hope one day to understand how decisions percolating through the brains of billions of people, often acting at cross-purposes, interact to chart the course of financial markets and national economies.

Inside the scanner, Belur made up her mind.

She decided to gamble her entire nest egg on her trustee's goodwill.

She pushed the button, putting her money in play.

With the ritual clang of the opening bell one day in February, the five trading floors of the New York Stock Exchange (news - web sites) abruptly surged in a whirlpool of profit and loss.

Hundreds of brokers waved cellphones, fingered small computer keypads and placed their clients' orders. Fortunes winked into existence and just as quickly vanished.

In all, about 1.6 billion shares — worth about $46 billion — changed hands during the day in a ripple of deals coursing through the global equities market. The daily behavior of buyers and sellers is so complex that even experts in chaos theory have been unable to discern a predictable pattern.

In virtually every area of markets, human behavior has economists stumped.

"We don't know why stock prices go up and down," said Caltech economist Colin Camerer. "We don't know why savings rates are so dramatically different in different parts of the world. We don't know why there is labor market discrimination."

People trust other people when economic theory says they should not. They cooperate when betrayal seems more rational. They gamble foolishly, overestimating risk when they are losing, and underestimating it when they are winning. They spend too much and save too little.

Economists know all this from personal experience, but they don't know how to factor the quirks of human behavior into their mathematical models. This is no small matter. Efforts to set interest rates, revamp health insurance, privatize Social Security (news - web sites), revise pensions, police the sale of securities and alter legal liability rules rely to some degree on economists' ability to make reliable predictions about the choices people will make.

"Economics has hit the wall," said Andrew Lo, director of MIT's laboratory for financial engineering. "It has explained about as much as it can with the tools it has. There are too many inconsistencies between theory and data."

Pioneers in neuroeconomics believe the key to understanding economic behavior lies deep in the brain, at the level of cells and synapses.

The brain is above all an economic engine forged by evolution through eons of scrounging for scarce resources, they argue. So the ability to trade things of value is the defining characteristic of the brain, the keystone of human character.

"Trade preceded agriculture; it preceded cities; it is a major component in human sociality. More than anything, it explains our success as a species," said Vernon Smith, an economist at George Mason University whose work in experimental economics earned him a Nobel Prize in 2002.

Some experts suggest that stock markets and other financial exchanges, as creations of the human intellect, may mirror the biological networks in the brain.

If only they can understand the brain, researchers believe, the mysteries of markets will be revealed.

Inside her scanner at Baylor, Tang made up her mind.

She signaled her decision with a tap of a button.

As the trustee, she had chosen cooperation. She split the proceeds of her partner's first investment evenly.

Isolated in the neighboring scanner, tracking her partner's decisions via icons on a computer screen, Belur had no way to know whether that choice was sincere or simply a strategy to encourage further investment until the odds would shift in favor of betrayal.

Even so, Belur gambled. On the next round, she once more invested everything she had.

Again, her faith was repaid. Tang shared the profits equally.

Tang, who was working on her doctorate in human genetics at Baylor, was drawn to the experiment not by scientific interest in its

outcome, but by the spending money she could earn as a volunteer. She had carefully planned how to win as much as possible in the experiment.

"I had a strategy," Tang explained later. "If she was nice to me, I would be nice to her. At the very last round, I would betray her."

A team of researchers led by Read Montague, director of Baylor's Human Neuroimaging Laboratory, and Baylor neuroscientist Brooks King-Casas scrutinized the synapses of both women for cellular evidence of the relationship building up between them.

The researchers used technology developed at Baylor that allows scientists to monitor two or more brains simultaneously using functional magnetic resonance imagers linked through the Internet.

For the trust experiment, funded by the Brown Foundation Inc. in Houston, the researchers often paired a volunteer in a brain scanner at Baylor with one at Caltech, more than 1,300 miles away. The researchers at Baylor and Caltech have conducted the experiment with 144 people — the largest interactive brain-imaging study ever.

So little is known about the biology of decision-making that researchers had no theory to test. They wanted to gather as much data as possible during the financial interactions in the hope that signatures of brain activity might emerge.

"In this game, trust builds up, and it must exist somewhere in the brain," said Caltech neuroscientist Cedric Anen. "But there is not one event where we can say, 'That is trust.' We don't know when it starts, how it builds up or what is involved."

The results, so far unpublished, reveal that financial dealings seem to engage neural networks in the cingulate cortex, an area of the brain involved in switching between tasks, monitoring errors and short-term memory.

In sprays of light on a computer screen, the researchers could see how levels of activity shifted. Men typically showed the greatest activity in the seconds before making an investment decision, women in the moments before they revealed their decision to their trading partner.

In Belur's and Tang's paired brains, the offers and counter- offers — signaled by pushing buttons inside their linked scanners — triggered heightened activity along a crescent-shaped strip of brain tissue in the cingulate that appears to track responsibility for social interaction.

With each round of negotiations between the two women, a reputation for fair dealing took hold in their neural tissues.

"Trust is one of those few notions that underlies everything from individuals making decisions together to huge policy questions between nations," said Steve Quartz, director of Caltech's social cognitive neuroscience laboratory. "For a long time, we thought this was a state beyond measurement.

"The brain scanner is beginning now to put a yardstick up against it, to provide a measure for it."

In deconstructing the biology of trust, other researchers have determined that the brain appears to prize that bond between two people biochemically, secreting a powerful hormone to cement working relationships.

The act of trust correlates with elevated levels of a brain hormone called oxytocin, the same chemical released during breast-feeding and uterine contractions, according to experiments done by researchers at Claremont Graduate University.

"It literally feels good to cooperate," said Paul J. Zak, director of the Center for Neuroeconomics Studies at Claremont. As the hormone level rose, people also were more likely to reciprocate trust. "The stronger the trust, the more the oxytocin went up, and the more trustworthy you were.

"Interestingly, participants in this experiment were unable to articulate why they behaved the way they did," Zak said. "But nonetheless their brains guided them to behave in 'socially desirable' ways — that is, to be trustworthy."

Inside the Baylor scanner, Belur invested another $20.

She signaled her decision, then awaited Tang's next move.

Was trust its own reward?

When a decision forms, the brain moves faster than self-awareness.

The brain unconsciously prepares to act a measurable length of time — up to 500 milliseconds — before a person consciously decides to act.

In other words, the brain is always one step ahead of itself, calculating the potential costs and benefits of each choice at a cellular level.

"Most of the brain is dominated by automatic processes, rather than deliberative [thinking]. A lot of what happens in the brain is emotional, not cognitive," said George Loewenstein, a behavioral economist at Carnegie Mellon University.

Some brain cells are especially sensitive to the potential rewards of decisions, research at Baylor and Emory University suggests.

Brain cells that release a chemical called dopamine, which serves as a reward to reinforce behavior, actually anticipate snap decisions to help balance costs and payoffs. The cells secrete a burst of good feeling beforehand to underline the desirability of one course of action versus another.

These neurons respond selectively. Some react only to the possibility of something beneficial and others only to the reward itself, researchers at the University of Fribourg in Switzerland discovered.

Every brain is of two minds about the future.

Two competing neural systems interact during choices that hinge on a conflict between short-term and long-term benefits, Harvard University researchers reported.

"Our emotional brain has a hard time imagining the future, even though our logical brain clearly sees the future consequences of our current actions," said Harvard economist David Laibson. "Our emotional brain wants to max out the credit card, even though our logical brain knows we should save for retirement."

Moral dilemmas can engage the same sense of fair dealing and mutual obligation as money matters. Researchers at Princeton University determined that synapses active during complex moral choices tapped into areas associated with rational thinking — and also into regions aroused by strong emotion.

"Some of that emotional architecture affects decisions we make involving money," Zak said.

Critics have often argued that volunteers playing experimental games in brain scanners are no measure of real market behavior. So researchers led by Lo at MIT studied working traders during their normal business day.

To measure brain activity indirectly, he wired 10 currency speculators at a Boston brokerage to sensors monitoring heart rate, breathing, blood pressure, body temperature and skin conductivity. By the end of the day, the traders had made 1,200 split-second trades, averaging $3 million to $5 million apiece.

His team plotted the biological indicators of stress, exuberance and tension against real-time profit and loss. He repeated the experiment at the Boston Stock Exchange.

Market trades, the sensors showed, were the stuff of sweaty palms, heavy breathing and pounding pulses. Snap judgments, honed by intuition, outweighed high-minded economic calculations.

These were "gut" decisions.

Contrary to traditional economics — which considers only rational deliberation — such measures of market panic and exultation begin to document how involuntary emotions affect the rise and fall of stocks.

Already, preliminary findings about the balance sheet of the brain have scholars rethinking the meaning of money itself.

The same reward circuitry activated by cocaine, sports cars, attractive faces and jokes is activated by money. Until now, economists have assumed that money was prized not for itself but only for what it could buy.

Moreover, the prospect of winning money activates specific brain regions in a way that the threat of losing it does not, researchers at Stanford University recently demonstrated.

Scientists are not sure how the electrical snap of synapses adds up to a financial decision, or how these insights might be assembled into a working theory of economic behavior.

"Sooner or later, you have to engage the issue of free will," said Glimcher, the New York University scientist. "When we finally understand the human brain, all human behavior will be predictable."

For nine rounds, the two women played in perfect trust.

Belur as the investor always put up the maximum possible. Tang, the trustee, in turn always equally divided the spoils.

Now, in the last round, the odds of betrayal reached their peak.

They had both reached the moment when economic theory suggested that the optimal move was for the trustee to seize all the profits because there would no longer be any way for the investor to retaliate.

Tang could cheat her partner without fear of reprisal.

The most rational move for Belur, therefore, was to refuse to risk any money in this last round, to end the game richer than her trading partner.

The women balanced on the cusp of betrayal.

Belur gambled again and put her entire stake in play.

The next 10 seconds of indecision seemed an eternity.

For one last time, Tang evenly split the proceeds of the investment.

"Perfect cooperation every round," said Baylor neuroscientist Damon Tomlin, who was monitoring the experiment from the control room.

The two women eased themselves out of the scanners, stiff and a bit dazed.

Unknowingly, they had defied the rules of game theory. They should have betrayed each other at the earliest opportunity. Had trust hormones triumphed over the theorem of self-interest?

By playing together in such harmony, each had earned 300 points, meaning each would be paid $30.

Tomlin counted out the one-dollar bills from a small lock box.

Tang eyed the growing stack of bills.

"If I had known it was the last round," she told Belur, "I would not have given you anything."

Tang could not explain why she lost track of her strategy, and it puzzled her.

There was no way she could know whether — in the instant of decision — the internal compass of her brain had altered her choice.