Wall Street's math wizards got crushed last summer when a global panic broke out. Are they playing a zero-sum game, or will they rise to power again?

Death by the Numbers

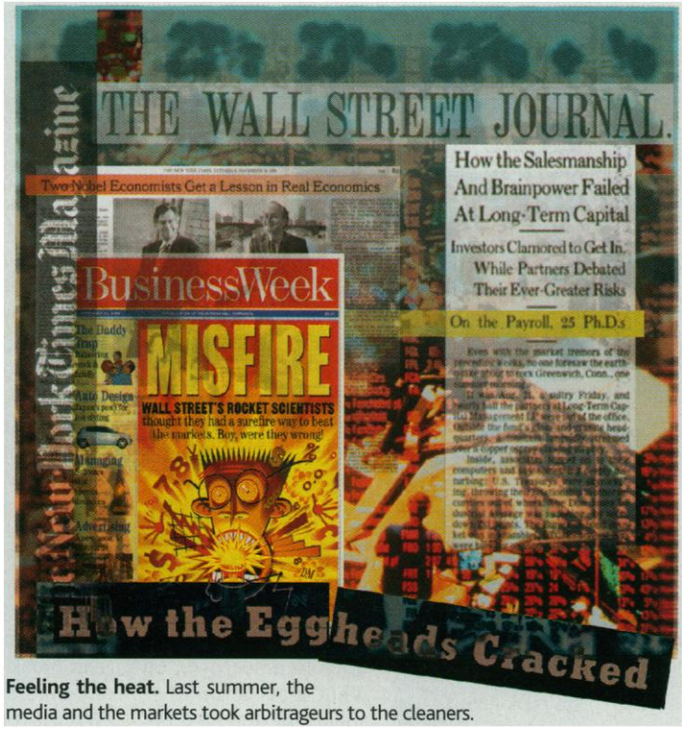
A physicist-turned–Wall Street trader is on the phone. It's late at night, and he's at home. Telephone lines at his office are tape recorded, principally to document trades, but it has a chilling effect that persists after he gets home. "This has to be anonymous," he begins. A source in New York agrees to meet for a hushed conversation over breakfast but later warns, "If you attach my name to any of this, I will make it my life's mission to hunt you down."

Welcome to the clandestine world of math and money, known as arbitrage. Strictly speaking, an arbitrage trade is one that earns money without risk or effort—if gold is selling for two different prices, for instance, you can buy low, sell high, and pocket the difference. A more modern definition would cover any trade that tries to profit from small market anomalies. Unlike most people, whose fortunes rise and fall with stock or bond prices, arbitrageurs ride the internal dynamics of the market, with trades artfully constructed so that, in principle, they make money whichever way the Dow goes. "We laugh at those guys who bet on which direction the market will move," one says.

Sometimes arbitrageurs make speculative bets, wagering, perhaps, that two companies will merge and their stock prices converge. But more often, the bets are highly mathematical, based on sophisticated computer programs that sniff for prices that are minutely out of joint. When one is found, traders borrow huge amounts of money and bet that the price will come back into line. As a well-known arbitrageur and former Columbia University computer scientist, David Shaw of D. E. Shaw & Co., once put it, arbitrage is "the search for 4.8 cent nickels."

Arbitrage may sound like a high-tech get-rich scheme, but it's practiced on huge scales by major investment banks and some "hedge funds," unregulated shops that try to turn large profits for wealthy investors. Hundreds of quantitative economists, mathematicians, and former physicists have been putting their skills to work in these places, picking apart the markets with the same tools used to model heat flow in nuclear reactors or solve abstract mathematical puzzles. The arbitrage culture is secretive: If the models leaked out, there would be too much cash chasing too few opportunities and mispricings could dry up.

The strategy seemed foolproof—until last summer's Russian financial crisis. On 17 August, Russia defaulted on its debt and triggered a global panic. Investors sold whatever they were holding and bought the safest things around, typically U.S. treasuries and German bonds. In the "flight to quality," tiny price anomalies flew wildly out of whack. "All of the classical relations that you rely on went out the window," says Leslie Rahl, an analyst with Capital Market Risk Advisors, a consulting firm in New York.



Feeling the heat. Last summer, the media and the markets took arbitrageurs to the cleaners.

The most widely publicized casualty was Long-Term Capital Management (LTCM), an elite hedge fund run out of Greenwich, Connecticut, that until then had seemed as solid as a bank vault, and one with a magical ability to breed money. If you'd invested with this company back in March of 1994, your money would have nearly tripled in value by the end of 1997. The firm was founded by trading legend John Meriwether and backed by the brains of two Nobel Prize winners and numerous finance Ph.D.s. "It was almost like that western *The Magnificent Seven*. The dream team was assembled, and they were just going to ride over the opposition," says Nicholas Dunbar, an editor at *RISK* magazine in London, which publishes mathematical finance papers.

By the end of the financial hurricane, however, LTCM had lost billions, and hemorrhaged 90% of its assets. Then word leaked out about problems elsewhere. In October, BankAmerica Corp. announced that it had lost $372 million on an investment with D. E. Shaw & Co. Some investment banks also took hits. "I happen to know a lot of guys who got fired," says one trader.

Many outsiders were quick to blame the catastrophe on mathematical hubris. Federal Reserve chair Alan Greenspan soberly remarked to a congressional committee, "No matter how skillful the trading scheme, over the long haul, abnormal returns are sustained only through abnormal exposure to risk." *Business Week* magazine's September cover read simply: "MISFIRE: Wall Street's rocket scientists thought they had a surefire way to beat the markets. Boy, were they wrong!"

But many traders interviewed by *Science* say the mathematical approach is a sound way to spin the market's inefficiencies into money, although it may need tuning as the marketplace becomes global. Some academics agree that the game is fundamentally profitable. "What this has demonstrated is that they need better models," says Andrew Lo, director of the Laboratory for Financial Engineering at the Massachusetts Institute of Technology (MIT). Indeed, the math wizards are already reemerging. The shakeup may even be good news, Lo says: "It just creates more opportunities in the market."

Fishing for loopholes

In a well-oiled market, most arbitrage oppor-

COLLAGE: C. FABER SMITH; BACKGROUND IMAGE: DAVID JEFFREY/IMAGE BANK

tunities are fleeting and hard to spot. Not always, though: A few years ago, the Italian post office inadvertently opened up a hole for arbitrageurs when it issued bonds that were substantially cheaper than equally secure bonds backed by the Italian treasury. Traders pounced. They realized they could buy the postal bonds, set up a skeleton offshore company whose only assets were the bonds, sell shares of the company for about the price of a treasury-backed bond, and pocket the difference.

According to an insider, representatives from major investment banks arrived at the Milan post office with cashier's checks for billions of dollars (one even had armored trucks filled with cash as a backup) to buy the bonds. Such simple arbitrage openings are rare, and they quickly evaporate once they're found. There are, however, more subtle opportunities. Many of them lie buried beneath the surface, in the prices of things called "derivatives."

A derivative is a financial instrument whose value depends on (is "derived" from) something else, often the price of a stock or bond. Simple examples are "call options" or "put options," which are contracts giving the owner the right to buy or sell something at a fixed price at a future time. An investor might buy a put option giving her the right to sell a share of IBM for $100 on 1 August (the "expiration date") as a kind of insurance policy. That way, if IBM's stock plummets, she can exercise the option and dump the stock at a reasonable price.

Options sound simple, but for years no one could figure out how much they should cost. If IBM ends up above $100, the put option is worthless. If IBM ends up at $90, the option is worth $10. But what's it worth a month before the expiration date when IBM is $95 a share? Tough question. Figuring out how to price an option was the Gordian knot of finance.

The breakthrough came in the early 1970s when economists Fischer Black and Myron Scholes discovered a clever link between options, stocks, and interest rates. The idea was this: Imagine buying a hypothetical put option that expires almost immediately. If you also buy just the right amount of the underlying stock, you are immune to what happens to the market in the next breath. That's because the combination is "risk-free"—if the stock falls a bit in value, the option is worth more, and vice versa. Since this hypothetical portfolio is risk-free, Black and Scholes reasoned, it should earn as much as an (essentially risk-free) treasury bond backed by the government. That meant you could take treasury bond interest rates, the current stock price, and calculate what this short-lived option should cost. That was half the eureka.

Can the Market Be Outwitted?

Arbitrage traders say the marketplace is filled with tiny anomalies that can be exploited for hefty profits (see main text). It's easy to see why such financial goofs might exist. On an average day, the Chicago Board of Trade swims with unshaven traders in sneakers and colored jackets, shouting, writing numbers on their hands, sliding on a floor covered in printouts and cough drop wrappers, leaping down stairs into the trading pits and exchanging fistfuls of money with silent hand signals. The bar upstairs is filled by 3 p.m. As David Weinberger, a well-known arbitrageur, puts it, "Think of the market as a black box. There are all these inputs: hope, fear, greed, hemorrhoids, hangovers, rational thought, irrational thought. All that goes in one end and out comes a price."

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—David Weinberger

Surprisingly, the human black box generally seems to spit out reasonable stock prices. New information—about corporate earnings, unemployment, or hurricanes threatening crops—is quickly incorporated into a stock's price. Most people who "beat the market" by picking underpriced stocks seem to be just lucky. *The Wall Street Journal* regularly pits top stock pickers against darts thrown at the stock pages. Stock pickers beat the darts about 60% of the time, but do no better than the Dow Jones Industrial average.

But are the markets really so efficient as to preclude arbitrage, with its mathematical tools for teasing out the anomalies other people overlook? "Put it this way," says University of Chicago economist Eugene Fama, "I wouldn't try it." But plenty do, and claim to be making money. And a growing number of economists have started to think about the market as something other than a well-lubricated machine. "I would say that the finance profession is becoming much more open to the idea that markets are not efficient," says Robert Shiller, an economist at Yale University.

As evidence that "irrational" factors can influence the market, Shiller points to days when the market has lurched dramatically even though the world was quiet. "People try to concoct what the news was. But to me it's clear that the news was the market itself," running on its own internal dynamics. The burgeoning field of behavioral economics has turned up market psychologies that can drive prices out of kilter. Some studies, for example, indicate that people tend to hold onto losing stocks, hoping they will rise, and eagerly sell-off winning stocks, regardless of what the news is.

And there is some evidence that math can identify the resulting anomalies and thus see into the future, when they will correct themselves. Andrew Lo of the Massachusetts Institute of Technology and Craig MacKinlay of the University of Pennsylvania found, for instance, that two stocks from related companies often do a little dance in which a movement in one may presage a movement in the other. So if one drops, the other may be temporarily overpriced.

"Stock prices are predictable to some degree," Lo says, and with effort you can make money forecasting them. In fact, when Lo and MacKinlay started to look at more recent market data, from after 1988, they found a surprising change. "Some of the patterns we had observed have now been very thoroughly mined away. Most of the effects are gone." The reason? Lo partially credits arbitrage traders at D. E. Shaw & Co. in New York. "David Shaw told me they were trading based in part on our studies," Lo says. "I was very flattered." But, he adds, "none the richer." **–D.K.**

To price a real option, whose expiration date was a ways off, required one more thing—a model of how stock prices move over time. Black and Scholes assumed the prices display what physicists call "Brownian motion." Like a raindrop falling in the wind, a stock price has a drift but also wiggles around. The wiggle, called the "volatility," can be estimated from historical data. Mix all this up with a little stochastic calculus and you have the Black-Scholes Equation—at the time the fanciest bit of math ever to make it into a trader's calculator. It wasn't perfect, but it gave investors a way to price options and the confidence to trade them in huge quantities.

Today, investors often buy options on stocks, interest rates, and commodities as insurance policies, or as cheap bets on which way the market will move. The pricing break-

through won Scholes and Harvard University economist Robert Merton, who extended the work, the Nobel Prize for economics in 1997. Both became central figures at LTCM.

With the new math came new opportunities to make money. Some firms started to specialize in pricing derivatives, making improvements to the Black-Scholes Equation and combing the market for derivatives that were selling for too much or too little. "This was real serious mathematics," recalls David Weinberger, a former Bell Labs mathematician who was the managing partner for the Chicago firm O'Connor & Associates in the 1980s. "We had a quantitative research group of about 40 people, 20 to 25 of whom had Ph.D.s in physics, electrical engineering, or math," says Weinberger. On a big trading day, O'Connor's maneuverings accounted for an enormous 5% of the volume on the New York Stock Exchange. "We made a lot of money," Weinberger says. The race for new ways to turn math into money was on.

Mind the gap. The difference between "swap" and bond yields widened unexpectedly when bond prices shot up in August, swallowing up traders.

All in the math

One opportunity arbitrageurs spotted lay in an offspring of the Black-Scholes Equation: volatility. Because volatility is folded into the price of an option, it can be traded like corn or anything else. And although the actual price of the stock might wander randomly, volatility—the range of its daily excursions—seemed mathematical and maybe even predictable.

To make predictions about a stock's volatility, arbitrageurs study how it has changed in the past. A pharmaceutical stock may have periods of wild speculation when a new drug goes into clinical trials, but quickly revert to more quiet meandering. This history is fed into models with names such as GARCH, or Generalized Autoregressive Conditional Heteroskedasticity. "Don't ask," says one expert. "It's pretty hairy." Modelers also throw in a variety of other factors to try to narrow the forecast, and they compare volatilities of similar stocks to see if one seems out of sync. Traders don't buy blindly, however. "You have to be a little concerned when things appear out of whack," Weinberger warns. "You have to say 'Why is this game available to be played?' "

Trying to place a bet on volatility alone is a little tricky, since changes in the underlying stock price can also affect an option's value. To remain independent of the overall lurch of stock movements, arbitrageurs go "long" (buy) the underlying stock or go "short" (borrow the stock, then sell it, promising to replace it later). A short position, for instance, rises in value if the stock goes down, since you can buy it cheaply and replace the shares you borrowed. That could offset a call option, whose value goes the other way. The balancing act is similar to the one Black and Scholes used to price an option.

So traders place their bets by buying the options and hedge by adjusting how long or short they are the underlying stock. When the option expires, the traders cash out. If the stock price volatility was as they expected, and not as advertised, they win. It's really "statistical arbitrage," one trader says. "It pays off 51% of the time."

Bond interest rates and prices also show volatility, opening another opportunity for arbitrage. Here the problem takes on an extra dimension. Bonds have a particular expiration date (a 1-year bond pays interest for a year). Options on them have a separate expiration date. Traders take the universe of bond-price options and interest-rate options (called swaptions because the interest rate is often packed in something called a swap) in the market and, from their prices, make a contour plot showing how the market thinks volatility will change as a function of the two expiration dates. The surfaces ought to be smooth—especially for points in the distant and unknown future. But sometimes they aren't. This summer, arbitrageurs bought swaptions on a bet that a dimple in the U.S. interest-rate volatility landscape would flatten out.

Arbitrageurs also scour the market for subtle internal contradictions. Traders noted that the planned European Monetary Union should eventually make the yield on, say, Italian bonds and German bonds converge. Last summer, volatility surfaces for German and Italian bonds were similar, implying that the market expected the two economies to merge, but the bond yields themselves remained far apart, as if the market was ignoring the merger. Only one outcome was possible, so the arbitrageurs took positions that would make money either way—whether the yields converged or the volatility surfaces diverged.

Feasting on crumbs

When arbitrage does pay off, the profit can be minuscule—in some cases, a hundred dollar investment may bring a penny payoff. Factor in the overhead costs of executing a trade, and many aren't worth doing at all, except in enormous volume. So while arbitrageurs page through academic journals looking for technical insights, they're also engaged in a humbler enterprise: borrowing money. At the time of the crash, LTCM had parlayed $4 billion in actual cash into some $100 billion in spending money.

The problem with borrowing lots of money is that at some point, the lender wants it back. And when the Russian crisis broke, banks wanted more and more collateral on the loans they'd made. Investors the world over were ditching their favorite stock or bond for the safety of German bonds and U.S. treasury bills. The shift pushed some arbitrage spreads the wrong way. Pricing gaps that were supposed to close yawned wider, and bets on the spread, instead of gaining in value, started to tank.

Worsening matters for the bond trades, the arbitrageurs had hedged sloppily. In the swaption gamble that the dimple in the U.S. interest-rate volatility would disappear, traders would have survived if they'd hedged by shorting swaps. But instead, they went with U.S. treasury bonds, which usually move in lock-step with swaps and were slightly cheaper to trade. As usual, the combination was supposed to isolate volatility and insulate the traders from overall market movements.

But in the panic, people bought U.S. bonds in record numbers and their price rocketed (see graph). To raise money to meet the banks' demands for collateral, hedge funds had to back out of the trades. Replacing the bonds they had shorted cost them hundreds of millions of dollars. They tried to sell off the swaptions, but during the crisis nobody was buying, and they went cheap. Many trades on stock volatility met similar fates. "It was wild craziness for

SOURCE: BLOOMBERG FINANCIAL MARKETS; IMAGE: JEAN MIELE/THE STOCK MARKET

3 weeks," Weinberger recalls, "In my entire history, I've never seen anything like that."

Some competitors watched LTCM's fire sale with a certain glee. "It was hypnotic," one recalls, "then sickening." Sickening because it started to happen to everyone. "It wasn't supposed to be so hard to sell," one trader says. "What we missed was that other hedge funds were doing the same thing. That wasn't an input to anybody's model." Traders usually think of the market as something external. But during the crash, "[arbitrageurs] looked around," says *RISK*'s Dunbar, "and realized they *were* the market."

Failure, QED?

To many traders, the crash simply reflected tactical mistakes—not having enough cash on hand, not putting themselves and imitators into the models. They point out that today, market relationships are already returning to normal. "If the hedge funds had had enough money to hold on, many of these bets would have paid off," one trader says. "They were trying to make too big a profit," agrees Doyne Farmer, a former theoretical physicist at Los Alamos National Laboratory who started Prediction Company, a quantitative finance group in Santa Fe, New Mexico. "LTCM [borrowed] to a degree that would give most of us indigestion."

Some outsiders agree, saying the hedge funds simply overreached. "This was a bad use of models," says Ron Dembo, a former Yale University mathematician who now runs Algorithmics Inc., a financial software company in Ontario, Canada. "The mathematics is beautiful, but it's based on very heroic assumptions." Among them, he says, is that everything won't go wrong at once, as it did last summer. Dembo says hedge funds should have crash-tested their portfolios to make sure they could withstand such a global stampede for quality bonds.

But others say the events of last fall show that arbitrage is a zero-sum game. "It's like a racetrack," says Eugene Fama, an economist at the University of Chicago who downplays the math involved. "These are plain old bets." Fama is famous for enthroning the notion of "efficient markets" (see sidebar). The basic idea is that market prices adjust intelligently and at lightning speeds. There is little room for true arbitrage. If you plotted the profit quantitative hedge funds make over many years, he says, "I bet it would be symmetric around zero."

Others think the arbitrage game is a winning strategy, but that the gains come at a cost. "My view is that it looks like they're selling insurance policies," says Duke economist David Hsieh. Sometimes, for instance, people may sell risky bonds or options too cheaply because they would prefer to sleep well at night. Arbitrage traders "insure" these people by taking the securities off their hands. Maybe the hedge funds were unlucky, Hsieh says, and catastrophe struck early. MIT's Andrew Lo adds that by buying unpopular bonds or options in large quantity, the arbitrageurs provide "liquidity," helping things move along and extracting a facilitator's surcharge.

But the insurance idea doesn't sit well with some arbitrage traders, because it implies that, from time to time, they are sure to lose big. "My nightmare is that we're just selling insurance," one says. He suspects that pricing anomalies are real, although it takes a lot of smarts and math to find them. "The set of market participants not paying attention is far deeper and vaster than the people who are doing arbitrage." Most people push and pull on one part of the market, he says, and in doing so throw it out of whack with respect to another part. In this view, arbitrageurs are like the deckhands on a schooner who scurry about tightening all the knots—and taking a healthy profit.

Whatever role arbitrage plays in the scheme of things, many suspect it will return from exile. Already LTCM appears to be back on track. Following a private-sector bailout this summer, LTCM made investors a healthy 11% by year's end. "We're not confirming that number, but it's accurate," a LTCM spokesperson says. A spokesperson for D. E. Shaw & Co. would not give numbers but says that "the firm is extremely robust and growing."

David Shaw's 4.8 cent nickels got expensive last summer, but, as another trader put it, "I think one day there will be 4.8 cent nickels again, even 4.2 cent nickels. There are opportunities out there right now."

–DAVID KESTENBAUM

CELL BIOLOGY

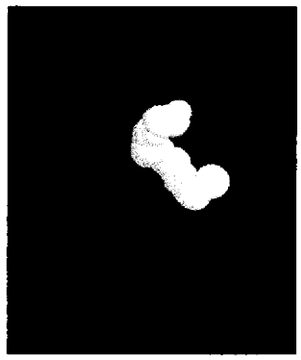
New Clues to How Proteins Link Up to Run the Cell

Recent work highlights the role of phosphate-bearing amino acids in bringing proteins together to control cellular activities

Proteins are at the heart of the biochemical machinery that makes a cell run. But unlike the parts of, say, a car engine, which are permanently bolted together, the cell's molecular cogs and wheels are constantly assembling and disassembling. Before each task, they must locate and latch onto the right partners in the congested workspace of the cell. Recently, researchers have been learning how protein elements called binding domains help control this regulated coupling and uncoupling.

The latest advance comes from cell biologist Kun Ping Lu and his team at Harvard Medical School, in the form of a new function for the so-called WW domain, a conserved amino acid sequence found in more than 100 proteins with diverse functions. Their report on page 1325 shows for the first time that the domain binds to other proteins only when certain of the serine amino acids in those targets carry a phosphate group. This suggests that in these cases, the domain controls a particularly important class of protein interactions: those that are turned on and off by signals within the cell.

Cells regulate activities ranging from division to self-destruction by tagging proteins with phosphate molecules. And by adding the WW domain to the small group of protein-binding domains that home in on phosphoserine, the new finding suggests that at least some WW domain–containing proteins play a key role in controlling those cellular processes. Lu compares the WW domain to the SH2 domain, which enables proteins containing it to link up with proteins that contain phosphorylated tyrosine amino acids and is extremely important in controlling cell growth, among other things.



CREDIT: KUN PING LU

Nestled in. The model substrate PEG (green) is attached to the phosphoserine-binding site (red) of Pin1.

Other researchers note, however, that the analogy may not be complete. "I'm not 100% convinced that all WW domains are going to bind phosphoserine in the same way that all SH2s bind phosphotyrosine," says cell biologist Ray Deshaies of the California Institute of Technology (Caltech) in Pasadena. "But I am persuaded that at least a fraction of them do."

And that is enough to make the result intriguing. "It is a very fascinating paper," says protein-signaling researcher Tony Pawson of Mount Sinai Hospital in Toronto, Ontario, and not just because it reveals a new function for the WW domain. It is also, Pawson adds,