# THE REAL DEAL

WITH INNOVATIVE ALGORITHMS AND POWERFUL COMPUTERS, ECONOMISTS ARE GETTING REAL WITH THE LIFE-CYCLE MODEL

Who among us hasn't pondered strange human behaviors? Some people invest in beanie babies. Some wear bell-bottom hip huggers. Some of us live in populous cities located in earthquake or flood zones.

Despite many irrational human behaviors, economists have the professional task of making reliable predictions about the economy, a task that involves trying to find underlying logic in the processes by which people make decisions in consumer spending, housing, employment, savings, healthcare and many other economic-related realms of activity. One of the best tools economists have to help forecast economic weather, despite the inherent vagaries of human decision-making, is the *life-cycle model*.

"The life-cycle model is one of the central paradigms in economics," says John Rust, professor of economics at the University of Maryland at College Park. "With this approach, observed behavior can be explained as rational 'best responses' based on the structure of economic institutions, such as the social security system, and the real uncertainties individuals face regarding health, earnings, prices and many other uncertainties."

The life-cycle model mathematically formulates decision-making as a series of sequential decisions influenced by variables over the course of a lifetime. It has been applied usefully in many areas of policy making. Nevertheless, the model's predictive ability has been limited because it hasn't been possible to solve complex formulations that account for a realistically broad range of variables. "The theoretical predictions of the model," says Rust, "haven't been well understood since, except for trivially simple special cases, the model doesn't have a closed-form solution."

Beginning several years ago, Rust used PSC's Cray T3E to develop novel algorithms that, for the first time, make it possible to apply the computational muscle of massively parallel systems to the life-cycle model. With this powerful approach, he and graduate students Joseph Nichols and Gaobo Pang have used LeMieux, PSC's terascale system, to solve the largest, most realistically specified versions of the life-cycle model ever attempted.

Their approach has yielded insights in a number of areas. Nichols, now at the Federal Reserve, used LeMieux to develop the first realistic life-cycle model treatment of housing and mortgages, resolving a previously puzzling question about why people hold a large fraction of investment in housing assets. A study by Pang used LeMieux and a detailed life-cycle model to find that, contrary to expectation, tax-deferred savings accounts would lead to substantial new savings and could induce earlier retirement.

With his innovative algorithms and LeMieux, Rust — an advisor to the Social Security Administration during the Clinton presidency — has applied the life-cycle model in many areas. Among several government-policy related studies, he developed and tested a proposal by which the Social Security Administration can improve its disability benefit process, targeting those who are truly disabled at less cost than current procedures.

"When the life-cycle model is fully estimated and tested," says Rust, "it has a number of practical uses for predicting the impacts of proposed changes to the Social Security program, including raising the early retirement age, introducing individual accounts, and changing Medicare coverage." Modeling these proposed changes instead of passing them with no prior study can protect the American public, says Rust, from becoming "inadvertent crash-test dummies."

Most interesting, perhaps, in Rust's work with LeMieux are the surprises that emerge from the ability to solve more realistic formulations of the model — such as his recent work on a long-puzzling question about decline in consumption after retirement. Contrary to prior studies, Rust's computations — taking into account variables not before considered — show that this decline is a rational response consistent with the life-cycle model. The result has stirred controversy.

"This is the power of computational economics," says Rust, "to arrive at results we're not able to anticipate by our economic intuitions from simpler versions of the model. It takes supercomputing to show how basically simple, elegant equations can yield answers we would never guess at or otherwise be able to see."

**John Rust,**
University of Maryland

"IT'S ONLY THROUGH WHAT THE SUPERCOMPUTER SHOWS US THAT WE CAN OPEN OUR EYES AND THINK IN NEW WAYS."

## BREAKING THE CURSE

How do you quantify the complexities of human behavior? Economists have wrestled with this problem since at least the 1940s, when researchers in a number of fields — notably John von Neumann and Oskar Morgenstern — arrived at an approach called "backward induction." In the simplest terms, backward induction means starting at the end and working backward to see what decisions led to the final outcome.

The life-cycle model uses backward induction and assumes that people try to make the best decisions possible, based on the information available to them. The beauty of the model is that it can accommodate uncertainty — saving for retirement being a classic example. No one knows, in a precise way, how much to save since no one knows how long they'll live or what kinds of health problems they might experience, not to mention future rates of inflation or other economic factors.

The life-cycle model, furthermore, is predicated on preferences and beliefs — such as individual priorities about leisure versus work or perceptions about future health and longevity. Rust's algorithms implementing the model are best described as "polyalgorithms" — an inner algorithm does the backward induction (often called "dynamic programming") within an outer algorithm that searches for values of the preferences and beliefs parameters. The inner algorithm solves the model hundreds or thousands of times to find optimal decisions and iterates back and forth with the outer algorithm until the predicted behavior matches well with observed behavior over the life cycle.

Although variables will change and details of the model specification differ, life-cycle models can be applied to a huge variety of problems. "The life-cycle model has the ability to provide an explanation for almost everything we do in our lives," says Rust, "starting with child rearing, learning and schooling, dating and sex, going to college, searching for the first job, getting married, buying a first home, choosing whether to have children and how many, saving for their college and your retirement, or deciding when to retire."

A serious limitation of the life-cycle model has been the so-called "curse of dimensionality." For each decision cycle, the program must find optimal values for the variables, and a single solution requires many billions of algebraic operations. For every variable added, increasing its realism, the computing time increased exponentially. Rust's novel algorithms introduce a randomizing routine that, in effect, breaks the curse of dimensionality. He achieves linear scaling on parallel architectures for as many as 800 processors, making it possible to solve problems that would take many hours on a single processor in a matter of minutes on a parallel system such as LeMieux.

Bellman equation for rental problem

$$V(r,d,o) = \max\left[EP(0) - \bar{D} + \beta EV(r_0,0,0),\ ER(r,d,o) - EM + \beta EV(r,d,o)\right]$$

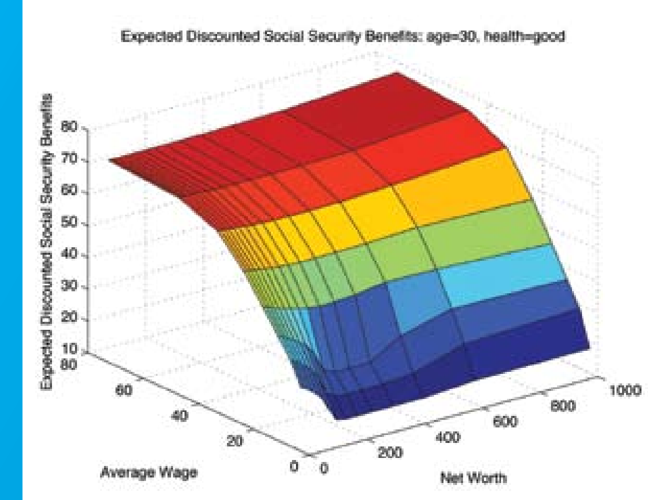

## HOW TO MAKE (MORE) MONEY RENTING CARS

In a much different application of his methods, Rust looked at a car-rental business and the question of what is the best timing to replace older cars with new models. Even in the case of a company making good profit, the modeling shows they could substantially increase profit by using cars longer with a "discount menu" rental rate.

"We found that the company is getting burned," says Rust, "by the rapid initial price depreciation in cars. By holding cars longer, they amortize the initial depreciation over a longer horizon, earning more rental revenue, which helps to defray the cost of replacing older with newer models."

The modeling also accounts for the economic reality that customers will be less inclined to rent older vehicles – showing that with age or odometer-based discounts on rental, the company can earn significantly higher profit, and customers have greater choice. "With PSC resources," says Rust, "we found a win-win situation that this company is seriously considering adopting."






Expected present value of social security benefits for a 30-year-old person in good health, as a function of average wage and net worth. (Units are in thousands of dollars.) Benefits are a concave function of average wage, showing that high-wage individuals have lower proportionate return than low-wage individuals, an indication of the "progressivity" of the system.

## THE PROBLEM WITH TOYS

Rust's recent modeling of retirement consumption goes beyond prior life-cycle modeling of this problem and suggests — contrary to prevailing wisdom — that, with a sufficiently realistic statement of the life-cycle model, retirement data that's been seen as "irrational" can be explained as a rational response. By taking into account the "labor-effect factor" — the possibility that people choose to retire earlier with less income than they otherwise might, because they value leisure — his modeling arrived at a new way of fitting the model with observed behavior.

Earlier this year in an invited talk at the Federal Reserve Board in Chicago, Rust stirred controversy when he presented these findings. Previous work on this problem has relied on a concept called "consumption smoothing" — which assumes people adjust consumption gradually in response to anticipated events. Skepticism about his finding, Rust believes, comes in part from reliance on life-cycle models — "toy models" — that don't account realistically for the choices people face as retirement nears. Consumption smoothing is a strong intuition that economists arrived at from toy models, and "it doesn't really generalize."

The inadequately specified "toy models" can lead to bad or unnecessary policy changes. "Some economists point to the drop in consumption after retirement as 'proof' that individuals are myopic," says Rust, "and experts therefore think that having a large, mandatory Social Security program is the way to protect these poor decision makers in old age and keep them out of poverty. My work indicates that the drop in consumption need not be a sign of myopia and can indeed be an optimal response by a rational, forward-looking consumer. In general, if people are rational, it only hurts them when the government forces them to save in a certain way, especially if it makes them save too much in the early part of their life when they are liquidity constrained."

Beyond the challenging theoretical insights from Rust's work, there are significant practical applications. From a public policy perspective, says Rust, being able to model human behavior at this level of detail is far more cost effective than attempting to measure behaviors in a population.

"These models can get so complex," he says, "that it's only through what the supercomputer shows us that we can open our eyes and think in new ways. This represents an important contribution to the science of economics that, I believe, will become more and more important over time — as the tools become more powerful and more economists learn to use them." (DA)

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