As a scientist working on breakthrough lighting technologies, Jeff Tsao is a firm believer in the magic of energy efficiency. After all, the numbers are compelling. Replace traditional bulbs with far more efficient light-emitting diodes (LEDs), and, studies suggest, the U.S. could cut the electricity used by lighting by at least one-half. Perform similar efficiency-boosting tricks with cars, buildings, appliances, and industrial processes, and the U.S. could slash greenhouse-gas emissions by at least 23 percent—and save money.

But a few years ago, Tsao, the chief scientist of a lighting research center at the Department of Energy's Sandia National Laboratories in Albuquerque, New Mexico, had a troubling conversation with a leading LED-industry executive. The CEO said that his company isn't in the business to save energy, Tsao recalls. Instead, the executive expected that LEDs would create whole new uses for light, so that people would buy a lot more LEDs than they did regular bulbs—and as a result, consume more energy.

That conversation caused Tsao and his colleagues to begin crunching their own numbers on the relationship between the efficiency of light and the amount of energy it consumes. Using historical data from around the world, they discovered that as the efficiency of light improved—as it did when oil lamps replaced candles, and electric lights replaced oil lamps—the use of energy jumped. "Each time the technology changed, the cost of light dropped dramatically and the consumption of light skyrocketed," Tsao explains.

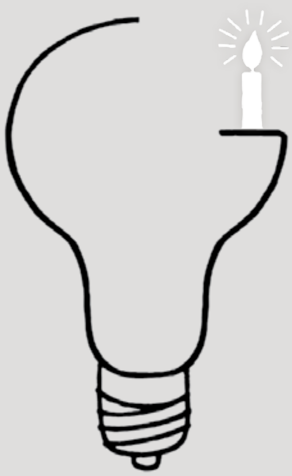
The spread of super-efficient LEDs, the researchers predicted, would continue that trend. LEDs could create "a massive potential for growth in the consumption of light," they concluded last year in the *Journal of Physics* (1). That's because LEDs are cheaper to operate

BY JOHN CAREY

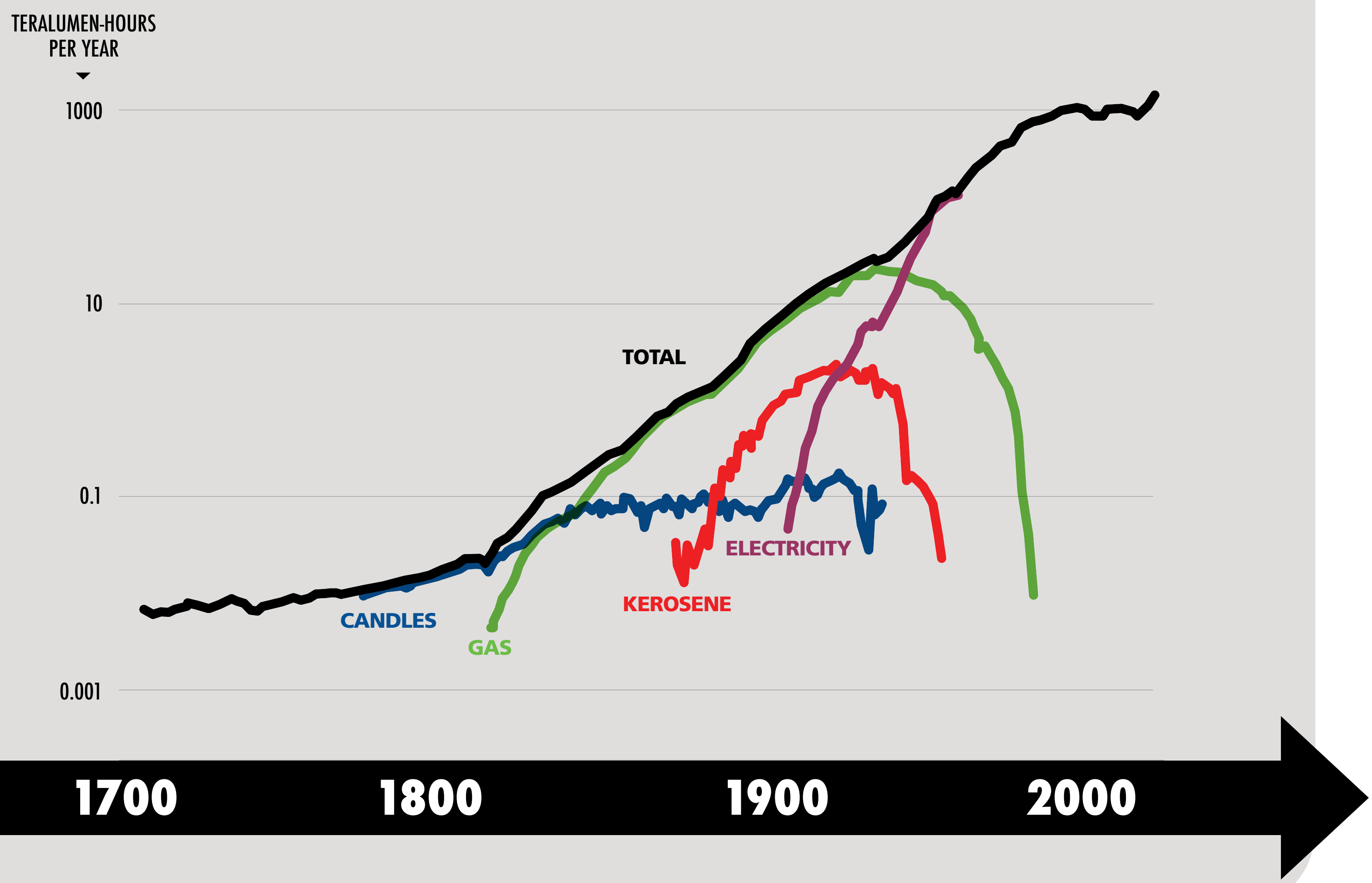
THE EFFICIENCY CATCH-22

The more energy we save,
the more we use

300 YEARS OF LIGHT



Ever since our ancestors first harnessed fire hundreds of thousands of years ago, humans have tapped various forms of artificial light to extend our days past sunset and brighten up the indoors. “Indeed, artificial light is so integrated into the human lifestyle as to be barely noticeable,” a team led by Sandia National Laboratories light researcher Jeff Tsao noted last year in a study published in the *Journal of Physics* (1). And over the past three centuries, our overall consumption of light (black line) has soared as new lighting technologies, such as electricity (purple) and kerosene (red), replaced gas (green) and candles (blue). These curves, taken from a study of light use in the U.K., show that as light production became more energy-efficient, consumption increased by five orders of magnitude—thus helping create a “rebound effect” that pushed up overall energy consumption. In large part, that’s because “lighting is consumed not to waste energy, but to increase human productivity,” Tsao’s group concluded; increased energy consumption “is simply the cost of that increased productivity.” Now, the question is whether new lighting technologies, such as light-emitting diodes (LEDs), will sustain that troubling trend—or make it a dim memory.



Source: Fouquet. R. and P.J.G. Pearson. 2006. Seven centuries of energy services: The price and use of light in the United Kingdom (1300-2000). *The Energy Journal* 27(1):139-178 and the technology could prompt consumers and architects to equip homes and offices with more and brighter lights. And LEDs could even "unleash new and unforeseen ways of consuming light," such as glowing floors, shimmering jackets and tablecloths, or walls that display ever-changing artwork. The increased LED-light consumption could quickly wipe out much of the energy savings, Tsao's team concluded.

That study is just the latest in a long line of studies that have arrived at the same counterintuitive conclusion. More than a century ago, an English economist named William Jevons noted that as the new steam engine and other technological advances made coal use more efficient, the use of coal soared. His provocative observation that efficiency improvements can actually cause energy use to climb is now known as the Jevons paradox—or the "rebound effect."

Now, new studies such as Tsao's are again suggesting that modern efforts to improve energy efficiency could lead to big rebound effects; they're touching a nerve and prompting debate in energy and climate circles. Governments and think tanks have launched studies of the paradox, and stories in the *New Yorker* and *New York Times* have even suggested that energy efficiency, far from being a savior, could actually be bad for the environment. "The stakes are actually pretty high," says Roland Geyer, professor of industrial ecology at the University of California, Santa Barbara, and coauthor of a recent review of the rebound literature.

On the Rebound

No one involved in the current debate doubts that rebounds occur. Nor is there much debate that rebound effects come in different flavors. First, there are so-called "direct rebounds." If you trade in your SUV for a Prius, for example, you'll save a lot of money per mile on gas, so you may decide to drive a lot more miles. As a result, much of the energy savings from the higher mileage would be wiped out.

Then there are indirect effects. If you drive your new Prius the same amount of miles as before, you'll have more money. Now you can spend that money on a vacation to Europe that will burn a lot of jet fuel—perhaps more than was saved by your car. Similarly, if a new process for making steel is more efficient, the price of steel will drop and builders will use a lot more of it. And if a new, more efficient technology creates whole new industries (as the steam engine did), then the economy can grow dramatically and use a lot more energy—though researchers argue about whether this really should be called a rebound effect.

The experts, however, do disagree about just how big rebounds can be. In a recent report, the Breakthrough Institute, a New York City–based nonprofit, reviewed a number of studies and issued a stark warning about the implications of rebounds. (2) "The more efficient that engines, motors, electricity generation and transmission, lighting, iron and steel production, computing, and even modern lasers have become, the more demand for each has grown," the report noted. The bottom line: "Rebounds are real and significant, with the potential to erode much (and in some cases all) of the reductions in energy consumption from efficiency improvements."

As airlines bought more-efficient jets that used less fuel, they were able to lower their fares. So more people were able to travel by air, and the number of trips soared.

If true, big rebounds pose a big problem for those advocating rapid efficiency improvements as a way to solve climate and energy problems. Efficiency advocates have "overstated the potential" of energy savings, says Roger Pielke, Jr., a University of Colorado political scientist and a senior fellow at the Breakthrough Institute. To ensure energy security and combat climate change by reducing greenhouse-gas emissions, he believes, governments will need to go far beyond just improving efficiency—they will also need to vastly increase supplies of clean energy. "In the end, what matters most is energy supply," he says, "not efficiency."

Seductive Message

But that's not what most governments are pushing. U.S. Energy Secretary Steven Chu, for instance, says that energy efficiency can bring major, inexpensive reductions in carbon emissions. "It is an extremely seductive message, which politicians love, that we can get gains through efficiency at little cost," says Harry Saunders, a Danville, California, business consultant who has been researching and modeling the rebound effect on his own time for two decades. But it's also wrong, he argues. As U.K. economist Leonard Brookes puts it: "There isn't a free lunch." Brookes, former chief economist at the U.K.'s Atomic Energy Authority (and former World War II R.A.F. pilot), has a key idea in the rebound debate named after him—the Khazzoom-Brookes postulate. Some rebounds are so big, the postulate says, that they completely overwhelm the initial energy savings they create, a concept economists call "backfire."

Not so fast, retort the advocates of aggressive action on efficiency. "It seems like this issue comes up every decade or so, but this time it has some staying power and needs to be dealt with," says John A. "Skip" Laitner, director of economic and social analysis at the American Council for an Energy-Efficient Economy (ACEEE) in Washington, D.C. Laitner and many others still see energy efficiency as the cornerstone of policies to reduce energy use and greenhouse-gas emissions—and they say that the lunch is still pretty cheap.

The fact is that rebounds just aren't that big, he and others argue. "The claims of large rebounds are not empirically substantiated, and there is increasing reason to think they are modeling artifacts," says Amory Lovins, chairman and chief scientist of the Rocky Mountain Institute, who for more than three decades has been one of the nation's leading apostles of the gospel of energy efficiency.

So who's right? The data show—and most experts agree—that direct rebounds are relatively small. For instance, Steven Sorrell of the University of Sussex, chief author of a 2007 UK Energy Research Centre report on the rebound effect (3), finds that direct rebounds are typically less than 30 percent—meaning that efficiency improvements still net a solid 70-percent gain.

Smaller rebounds make sense when you think about human behavior, many researchers argue. For example, will you really drive that new Prius a lot more than your old SUV? Probably not, suggest studies by Lee Schipper, a senior research engineer at Stanford University's Precourt Energy Efficiency Center in California, and others. After all, your commute doesn't get any longer.

Similarly, you're unlikely to crank up the thermostat in winter just because you've installed a higher-efficiency furnace. In Vermont, for example, a concerted effort to boost energy efficiency in dairy farms, ski resorts, homes, and offices didn't bring an increase in energy use. On the contrary, the state now uses 10 percent less energy than past forecasts predicted it would, says Michael Dworkin, director of the Institute for Energy and the Environment at Vermont Law School in South Royalton and former chair of the Vermont Public Service Board. "I regard that as pretty strong evidence for a lack of a rebound effect," he says. "If there is an elephant in the living room, why didn't we stumble across it?"

There are some exceptions. Big rebounds can occur when energy costs represent a large share of the total cost of a product or service; that's because efficiency gains bring big reductions in cost. A classic example, says Stanford's Schipper, is air travel: as airlines bought more-efficient jets that used less fuel, they were able to lower their fares. So more people were able to travel by air, and the number of trips soared. But such cases are relatively rare, he says.

Efficiency or Wealth?

The situation gets murkier, however, when economists look at indirect effects. Will you spend the money you saved on gas for that European vacation? Or might you invest in new technologies that do more things, such as a super-efficient new computer that offers so many new applications and capabilities that you'll use it far more than the old one?

Harry Saunders's economic modeling suggests that the answer to questions such as these is "yes"—that indirect rebounds can be as large, or larger, than the initial savings from the more efficient technology. That would help explain why the U.S. now uses 40 percent more total energy than it did in 1975 despite the introduction of much more efficient cars, computers, and appliances.

But those models are far from definitive proof, efficiency proponents say. "Harry is an honest and nice guy, but he has not realized that his modeling is confused," says Lovins. One problem, he says, is that the models suffer from incomplete data, which causes an unrealistically wide variation in the rebound size among different parts of the economy. (For his part, Saunders accepts some of this critique, saying he hasn't been able "to come up with a clean explanation" for the variation).

There's a larger question here as well. Are energy-efficiency gains really the key factor underlying economic growth and increasing energy use? Consider the advances that Jevons observed more than a century ago. Then, the invention of steam engines, the Bessemer process for making steel, and other improvements slashed the price of everything from power to coal mining. That made it possible to build a vast rail network which in turn carried coal more cheaply to far-flung factories. The resulting leap in productivity "was the basis for the Industrial Revolution," says U.K. economist Brookes. The birth of modern industry also had some very big indirect effects, he adds: It propelled vast increases in wealth and population—which ultimately translated into big increases in energy use.

But it's not correct to say that efficiency gains caused the growth in energy, argue the efficiency advocates. Schipper, for instance, has a "new 37-inch LCD TV [that] is twice the area of my old 28-inch tube TV but uses one-third less energy," he says. But was the new model's improved efficiency the "cause of my buying a bigger TV? No." The real cause, he says, was wealth: Schipper could afford the bigger screen. And the industrial world's wealth is, in large part, the result of productivity gains from new technologies—from computers to cell phones, which also just happen to be more efficient. "The reason we are using more energy now is because of new technology, not because of energy-efficiency improvements," says Schipper.

Amory Lovins agrees. He argues that transformational technologies—such as the electric motor or the Internet—typically aren't invented to save energy. "People wanted a more convenient way to turn a shaft or move information around," and the increased efficiency "was a side effect," he says. The upshot is that "rebound is not the correct description of what's going on" and policy makers shouldn't let the debate distract them from aggressively pursuing major energy-efficiency improvements—now.

In the end, what matters most is energy supply—not efficiency

Meeting of the Minds

Without more hard data, it's impossible to put a firm number on indirect rebound effects and settle this debate. Yet the two sides may not be as far apart as they appear.

"When we step back and sum up what's what, everyone is saying energy efficiency is a great thing and we should do more of it," says Ken Ostrowski, senior partner in the Atlanta, Georgia, office of consulting giant McKinsey & Company. He's the coauthor of a landmark 2009 McKinsey report (4) that found $700 billion in possible savings from efficiency gains. Even Pielke, who calls for dramatically expanding clean-energy supplies, says, "efficiency is really important; we should be pursuing it at every opportunity." Adds Lovins: "We have to invest in the best buys first—and we get the most benefit per dollar with efficiency than with supplying more energy."

The two sides even generally agree that there is an effective—if politically challenging—way to prevent big rebound effects: raise the price of energy. It's basic economics. When oil prices plunged in the mid-1980s, for example, Americans flocked to buy gas-guzzling SUVs. When oil prices rose, the SUV craze stalled. Similarly, Tsao's LED study found that a relatively small 12-percent rise in the price of energy would prevent the rebound effect caused by switching to more efficient lights.

So, when efficiency makes energy cheaper, there's an "obvious conclusion," says the U.K.'s Sorrell: add an energy tax or carbon price to keep prices from falling very much while continuing to push hard for efficiency. Set correctly, the price will still allow consumers to save money while dampening potential rebound effects. And Pielke has an idea for how the government could use the extra revenue: for funding the development of clean, cheap energy sources.

Such win-win solutions, however, face tough opposition from anti-tax politicians. And rebound skeptics worry that the Jevons paradox could be used—misused, they say—to justify inaction on energy efficiency. In the past, Schipper recalls, the U.S. auto industry fought higher fuel-economy standards by claiming that improved efficiency wouldn't save oil, since people would just drive more. Now, efficiency supporters fear that argument will be echoed by other industry groups. "I find no other topic as abused with malice," says Schipper.

For the moment, the rekindled rebound debate is illuminating the complexity of solving energy and climate problems—and showing that it is hard to view efficiency as a completely free lunch. That was the lesson Jeff Tsao took home from his foray into looking at the consequences of LEDs. "Energy efficiency is still a good thing," he says. "But it's not quite so simple a good thing." ❧

Veteran science and environment writer **John Carey** has served as a senior correspondent in *Business Week*'s Washington Bureau, as an editor for *The Scientist,* and as a writer for *Newsweek,* where he covered science, technology, and health.

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