

For the specialism to emerge and grow, data scientists will have to overcome barriers that are common to multidisciplinary research. As well as acquiring understanding of a range of science subjects, they must gain academic recognition. Journals such as the *Data Science Journal* should become more prominent within the computing community. Software products and technologies should be valued more by academic committees.

New interdisciplinary courses will be needed. The University of California, Berkeley, and Stanford University in California have set up introductory courses for computer scientists on big-data techniques — more universities should follow suit. Natural scientists, too, should become familiar with computing and format issues.

In my lectures for computer-science graduates, I have brought together students at the University of Southern California in Los Angeles with researchers at the JPL. Using real projects, my students see the challenges awaiting them in their future careers. I hope to employ some of them on the projects that will flow from the JPL's big-data initiative. The technologies and approaches that they develop will spread beyond NASA through contributions to the open-source community.

Empowering students with knowledge of big-data infrastructures and open-source systems now will allow them to make steps towards addressing the major challenges that big data pose. ■

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Fuel-efficient cars cost less to run, so people might use them a little more.

# The rebound effect is overplayed

Increasing energy efficiency brings emissions savings. Claims that it backfires are a distraction, say **Kenneth Gillingham** and colleagues.

**B**uy a more fuel-efficient car and you will spend more time behind the wheel. That argument, termed the rebound effect, has earned critics of energy-efficiency programmes a voice in the climate-policy debate, for example with an article in *The New York Times* entitled 'When energy efficiency sullies the environment'<sup>1</sup>.

The rebound effect idea — and its extreme variant the 'backfire' effect, in which

supposed energy savings turn into greater energy use — stems from nineteenth-century economist Stanley Jevons. In his 1865 book *The Coal Question*, Jevons hypothesized that energy use rises as industry becomes more efficient because people produce and consume more goods as a result<sup>2</sup>.

The rebound effect is real and should be considered in strategic energy planning. But it has become a distraction. A vast ▶

► academic literature shows that rebounds are too small to derail energy-efficiency policies. Studies and simulations indicate that behavioural responses shave 5–30% off intended energy savings (see ‘Bounce back’), reaching no more than 60% when combined with macroeconomic effects.

There is ample scientific evidence to diminish undue concern about rebounds and bolster support for energy-efficiency measures.

Many countries are considering legislation to limit energy demand, oil imports and pollution<sup>3</sup>. China plans to reduce its energy intensity by 16% from 2010 levels by 2015; the European Union aims to cut energy use by 20% compared with 2020 projections; and Japan seeks a 10% drop in electricity demand from 2010 levels by 2030. Energy efficiency could contribute to the savings, but no country is taking full advantage of its potential.

Various factors slow the uptake of efficient technologies, including behaviour, high cost and split incentives between investors and beneficiaries. Energy standards could help. Last year, the United States extended its fuel-economy standards for cars and trucks to require a doubling by 2025. Even taking rebound into account, we expect that these standards will yield substantial net energy savings.

#### FOUR EFFECTS

A rebound effect manifests in four ways, each of which makes energy-efficiency policies less effective. The important question is by how much.

The ‘direct’ effect occurs when a drop in the price of using an energy service causes a rise in demand. Analysts infer the size of the effect from changes in people’s behaviour as prices vary. Numerous studies show that increased driving due to improved fuel economy reduces intended energy savings by 5–23% at first, rising to around 30% after several years as people get used to the lower cost<sup>4</sup>. The initial direct effect for home electrical appliances is also around 10% (ref. 5).

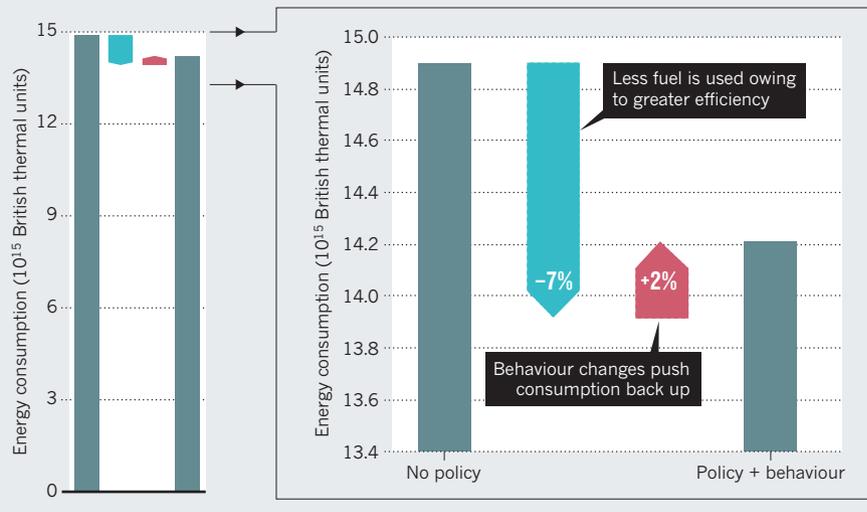
Because people respond more strongly to price than to efficiency cues when deciding how much energy to use<sup>6</sup>, these numbers are overestimates. The direct rebound effect for efficiency alone should be nearer the low end of this range, or around 5–10% (refs 4,5).

Money saved through efficiency can also be spent on another product, such as a new phone, causing an ‘indirect’ rebound effect if extra energy is needed to manufacture and use the additional item. Assessments of household spending indicate that 5–15%

**“Rebound effects are small and are therefore no excuse for inaction.”**

### BOUNCE BACK

US policy to double fuel economy standards by 2025 would reduce projected energy consumption by almost 7% in the absence of behaviour changes. A conservative estimate of rebound effects from driving more and purchasing additional goods limits energy reductions to around 5%.



of energy-efficiency savings are displaced in this way<sup>7</sup>. If the cost of making efficiency improvements is included, then the indirect effect is at the low end of this range. A Toyota Prius, for example, is more expensive than a comparable but less-efficient car, reducing the spare money available.

Two other rebound effects apply on the scale of national economies. The latest fuel-economy standards passed by the United States will reduce demand for oil there. But, because that will drive down the price of oil globally, they could encourage people elsewhere to drive more, leading to a ‘macroeconomic price’ effect.

Greater energy efficiency could also spur pockets of industrial growth, leading to a ‘macroeconomic growth’ effect. Higher energy efficiency in one sector can create opportunities or technologies in others that consume more energy. For example, the development of lighter, stronger materials for fuel-efficient cars might lead to better aeroplanes, boosting energy use in the aviation sector.

Macroeconomic rebound effects are hard to pin down, but simple economic theory sets a limit. Standard assumptions linking supply and demand suggest that ‘backfire’ due to the price effect is impossible: if global demand for oil falls, the oil will become cheaper, so the incentive to produce it will be reduced. Less oil will be used overall, even though the cost is lower.

#### COMPLICATED SUMS

The four rebound effects cannot simply be added together to give the combined effect, because the presence of one may erode others. For example, when both the direct and indirect apply, the result is less than the sum of the two because any direct rebound effect

decreases the amount of money available to spend elsewhere. Macroeconomic models estimate total combined rebound effects to be in the range of 20–60%<sup>8,9</sup>.

In sum, rebound effects are small and are therefore no excuse for inaction. People may drive fuel-efficient cars more and they may buy other goods, but on balance more-efficient cars will save energy.

Energy-efficiency measures should be on the policy menu to curb energy use and to address global warming. Stricter energy-efficiency legislation should be considered across all sectors, alongside options that are not subject to rebound effects, such as carbon pricing. ■

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