More is less

Economists and governments lag decades behind Derek Price's thinking.

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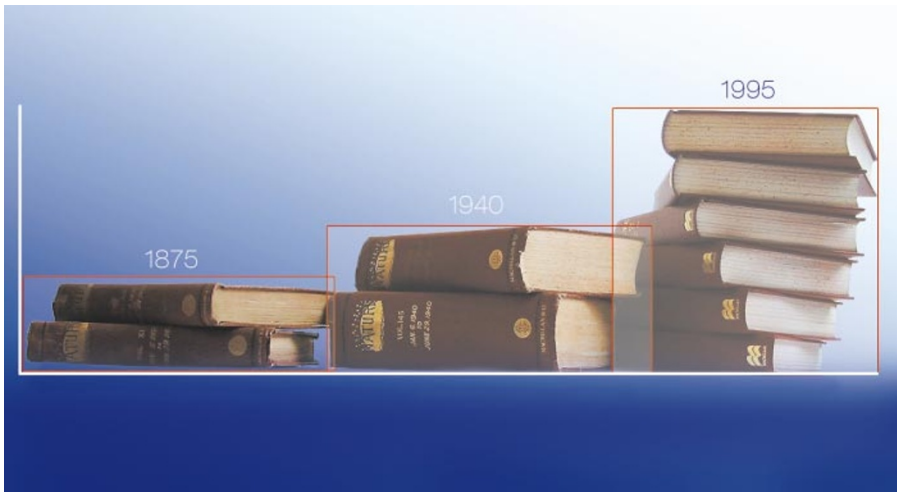

Bigger and better? The quantity of material published in *Nature* (not to mention its growing number of 'sister' journals) mirrors the exponential growth of all areas of science.

"Eighty to 90 per cent of all the scientists who have ever lived are alive now". This statement has been true for every year since 1700, perhaps even earlier. Moreover, "any scientist, looking back at the end of his career, will find that 80 to 90 per cent of the scientific work [in his field] has taken place before his very eyes". Every retired scientist is a walking, living, eye-witnessing historian of most of the science that has moulded his or her discipline.

This is how Derek de Solla Price opened his book *Little Science, Big Science* (Columbia University Press, 1963). These aphorisms are well known, but few remember the man who coined them, nor how he discovered them, nor how well he wrote about them. Even fewer people have internalized their significance.

Price was an ex-physicist who decided to "turn the tools of science on science itself", and his findings were memorable. He plotted, for instance, a graph showing the numbers of scientific journals founded since the first two — the *Philosophical Transactions of the Royal Society* and the *Journal des Sçavans* — were launched in 1665. This showed that science's exponential growth over the last three centuries has been astonishingly steady.

Although the graph does not adjust for the journals that fail, the doubling time since 1700 in the numbers of journals has been around 15 years and, because journals expand in size, the doubling time in the numbers of papers has been about 10 years. And, as far as Price could chronicle, the doubling time in the numbers of scientists and engineers has, since 1700, been between 10 and 15 years. So we see that, depending on the parameter measured, the entity we call science has, over the past three centuries, doubled in size every 10 to 15 years.

How different from non-scientific history! Most historical events took place long before any of the readers of this article lived, and, although human populations are growing, the majority of people who have lived will always be dead.

In other graphs, Price showed that many other measurable aspects of science also show tightly predictable rates of exponential growth. For example, the numbers of papers published annually with different multiples of authors can be extrapolated into the future, as can the asymmetric distribution of the numbers of papers published annually per author (Lotka's law), the numbers of universities founded annually, and the likelihood of any discovery being made independently.

We scientists are, these days, no longer much excited by such data because we have grown only too familiar with citation indices, impact factors and other quantitative tools of research harassment, but Price, on whose work those academic punishments are largely based, despised them as "counting nonsense". Price saw his work as a contribution to economics — but there he was to be disappointed, for the economists have ignored him.

And the loss has been theirs. There is an extraordinary school of economics currently rampant called 'endogenous growth theory' which is based on a series of beliefs about science that Price exposed as errors a third of a century ago. Such errors might not matter, except that the US and UK governments, to name but two, have based their policies for long-term economic growth on the theory.

The theory states that economic growth depends on scientific and technological advances — which is true — yet it also proposes that science, miraculously, is like a perpetual motion machine, in that if you know twice as much science you grow four times as rich (so you can afford four times as much science, and so on). But, as Price showed, science demonstrates diminishing returns. The rate of scientific growth is about twice that of economic growth, which means that you have to do four times as much science to get twice as rich. One day, as science's exponential demands on national incomes become excessive, the rates of scientific — and therefore economic growth — will slow.

> Science grows at twice the rate of the economy — so you have to do four times as much science to get twice as rich.

Moreover, endogenous growth theory states that, because science is universally available, it must be funded by the state. Well, science may need state funding, but not because it is universally available. As Price showed, science is organized in "invisible colleges", each consisting of a microdiscipline of a few hundred researchers who understand the field and its tacit, unpublished lore; but people outside the invisible colleges are disenfranchised, and a paper in high-energy physics is almost as obscure to a biochemist as to a historian.

Finally, the endogenous growth theorists are excited by their discovery that skilled people emigrate from poor countries to rich ones — something Price described as "the brain drain" decades ago.

There are few more important topics than the economics of science, but we scientists have erred in entrusting it to economists. By ignoring Price, they have incubated 37 years of mistakes. ■

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