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Adolph Menzel's 1873–75 *The Iron Rolling Mill (Modern Cyclops)*.

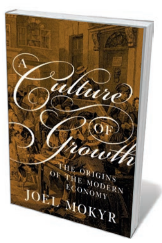
ECONOMIC HISTORY

The roots of growth

Brad DeLong examines a study that places the origins of the Industrial Revolution in fifteenth-century Europe.

What is modern economic growth? Going by the best available measure (it might be more honest to say 'guess'), today's average material living standards and economic productivity levels are some 20 times what they were in the agricultural era (about 6000 BC to AD 1500). And the efficiency with which humanity uses technology and organization to transform resources into useful commodities is currently growing at 2% per year — perhaps 100 times the rate common before the Industrial Revolution.

Some think that the current rate will slow down. But very few see it coming to a rapid end, unless there is a nuclear war or an equivalent catastrophe. The slowing will come as low-hanging fruit is picked and resource scarcities bite; but resource exhaustion followed by crash, as described in Jay Forrester's 1971 *World Dynamics* (Wright-Allen Press), is likely only in systems in which scarce resources are not rationed by high prices.



A Culture of Growth: The Origins of the Modern Economy
JOEL MOKYR
Princeton University Press: 2016.

What set the stage for industrial expansion and unleashed the virtuous spirals that drive growth? One school of thought sees the causal origins of modern economic growth in Europe as the emergence, from the late fifteenth to the mid-eighteenth centuries, of an elite dominant group focused on applying the cumulative increase of knowledge to human betterment. This school has plausible arguments, but is far from being a rough consensus, a majority opinion or even a plurality. Now one of its leaders, the economic historian Joel Mokyr, has written *A Culture of Growth* — his most successful brief thus far.

The axis around which Mokyr's argument turns is the "Republic of Letters": the "market for ideas" that spanned Europe from the era of exploration to the end of the Enlightenment. In it, the continent's intellectuals competed for reputation and patronage. Reputation was gained by creating and disseminating ideas, valued according to their empirical validity. Most patronage followed a beneficiary's reputation, not his or her prowess at flattery. Meanwhile, the political fragmentation of Europe created bolt-holes for rebels whose views offended their rulers — often gaining them the patronage of those rulers' potentially hostile neighbours. Ideas leaked back across borders, so rulers could not suppress thought even within their own realms. This created an ideological unity that spanned the continent among intellectuals of the 'republic'.

In Mokyr's view, the Dutch humanist Desiderius Erasmus launched the republic, in the late fifteenth century. Later, the English philosopher Francis Bacon focused on the value of empirical testing, or "experimental philosophy", as the best way to generate knowledge. His utopian 1627 *New Atlantis* provided a template for those who aspired to join the 'republic' — and was the first key that would unlock the door to modern economic growth. The emphasis on mathematics as an analytical tool, championed by Johannes Kepler, Galileo Galilei and Isaac Newton, was the second key.

But more important than any individual — even Newton — was that perhaps 10,000 well-educated Europeans thought of themselves as participants in the search for useful knowledge. Knowledge flowed between them and the tens of thousands of "trained engineers, capable mechanics, and dextrous craftsmen", the (rather few) industrialist-inventors such as Josiah Wedgwood, and the (rather more) entrepreneurs who had little abstract interest in science or innovation, but found that in a competitive market economy, the dynamic few drag along the inertial many.

As Mokyr shows, no other civilization had ever developed a set of institutional practices — such as academies, or disputes resolved by appeals to experiment — that had been adopted by an intellectual cadre so effective at generating incentives to create, discuss, modify, test, disseminate and use ideas. Before 1500, European intellectuals had not outstripped their counterparts in China, India or the Arab world in terms of numbers, or of ferocity in knowledge acquisition. (Rather the reverse, as English words derived from Arabic, such as algorithm, show.) Yet by 1800, Europe was far ahead in the amount of valid scientific or applicable technological knowledge generated over those three key centuries.

Not all economic historians agree with Mokyr's analysis. Robert Allen's impressive *The British Industrial Revolution in Global Perspective* (Cambridge University Press,

2009) places the origins of the Industrial Revolution in the British Midlands in the eighteenth and early nineteenth centuries. In Allen's view, the only route to modern economic growth required an array of elements never seen together before in Britain. Among them were high, imperialism-driven wages; cheap coal next to an ample canal network; and an open trading network allowing for a vast expansion of textile exports. .

There are other well-argued views. Michael Kremer holds that the roots of economic growth lie in the drift of the long run of history: growing populations intent on improving productive efficiency added to the accumulated knowledge behind technological innovation, adaptation and deployment. Avner Greif, Daron Acemoglu, Simon Johnson and James Robinson maintain that a virtuous circle of growth was set in motion by British institutions that emerged between 1500 and 1800, making economic cooperation and exchange more attractive than extracting wealth at the point of a spear (or a writ). It might have been luck. Or it might have been a combination of factors that do not correspond neatly to how subdiscipline-focused historians and social scientists have conceptualized the issues.

> ***"Perhaps 10,000 educated Europeans thought of themselves as participants in the search for useful knowledge."***

Is Mokyr's argument correct? For me, the balance of probabilities favours Allen's explanation above. Yet I do not think there will be consensus on this issue. And I would not be greatly surprised if I were wrong, and Mokyr's brief — for it is a brief, and not a balanced presentation of the live possible theories — turned out to be the most broadly correct analysis.

Mokyr concludes with a broadside. He accuses most of us concerned with the causal factors of the Industrial Revolution of taking too narrow a view of what it actually consisted of. To him, the mechanisms through which early European intellectuals affected technological progress are deeper and more complex than simply, 'How much science was needed to build a spinning jenny?'. Industrialization also heralded waves of science; they grew in tandem. Ultimately, without the impetus of science, economic growth would have fizzled out after 1815. *A Culture of Growth* is certainly making me rethink. ■

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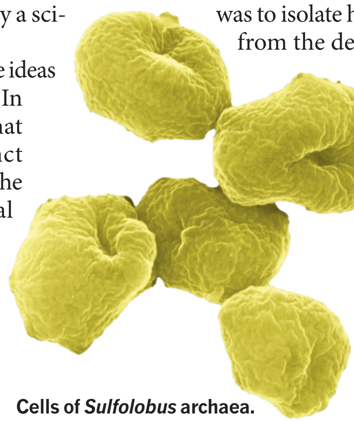
EXTREMOPHILES

Life at the deep end

Sonja-Verena Albers reviews a riveting chronicle tracing the discovery of archaea.

In *Microbes from Hell*, molecular biologist Patrick Forterre narrates the intriguing history of the discovery of archaea, single-celled microorganisms with no distinct nucleus that may have evolved as long ago 4 billion years. It was Forterre who, in the 1980s, found that certain archaea wind their DNA using reverse gyrase enzymes, which work differently from the gyrase found in bacteria. This is history told by a scientist who helped to make it.

Forterre was fascinated by the ideas of microbiologist Carl Woese. In the 1970s, Woese realized that 'archaebacteria' were distinct from bacteria, for instance in the sequences of their ribosomal RNA. In 1990, Woese and his colleagues proposed to divide life into three domains: bacteria, archaea and eukaryotes. The concept has gradually been accepted, but Forterre — with microbiologists Wolfram Zillig and Otto Kandler, among others — was an early 'believer'.



Cells of *Sulfolobus* archaea.

EYE OF SCIENCE/SPL

As he relates, most of the archaea that had then been isolated were extremophiles. These include hyperthermophilic microbes that thrive above 80 °C and are typically found in habitats such as deep-ocean vents. Up to the 1970s, the consensus had been that most such habitats were hostile to life, but a handful of groundbreaking microbiologists changed that. Thomas Brock, for instance, began to isolate hyperthermophilic archaea, including the genus *Sulfolobus*, from hot springs in Yellowstone National Park, Wyoming. Later, German microbiologist Karl Stetter showed that many surprising habitats, even oil fields, teemed with microbial life.

In the 1980s, Forterre began to analyse the hyperthermophilic archaea isolated by Stetter and Zillig, looking for reverse gyrase. The enzyme causes the DNA double helix to cross over on itself (supercoiling), and Forterre discovered that hyperthermophiles contain a form of it that induces positive supercoiling — adding extra twists. This enzyme, also found in hyperthermophilic bacteria, has not yet been seen in organisms growing at lower temperatures, leading to speculation that it might be one reason that hyperthermophiles can grow at such high temperatures. One theory is that the enzyme is important in sensing unpaired regions in hyperthermophile genomes, then initiating repair.

Microbes from Hell
PATRICK FORTERRE
(TRANSL. TERESA LAVENDER FAGAN)
University of Chicago Press: 2016.

In 1999, Forterre and his technician (later wife) Évelyne Marguet joined the AMISTAD expedition of the French National Center for Scientific Research and the French Research Institute for Exploration of the Sea. Its aim was to isolate hyperthermophilic archaea from the deep eastern Pacific Ocean. Marguet gives a rousing account of her 2,600-metre dive in the submersible *Nautile* to gather samples from 'smokers'. These rock chimneys form at geologically active sites on the sea floor, where superheated, metal-laden water is funnelled from vents.

Back on the ship *Atalante*, Marguet was enthralled to see cells growing in cultures from her samples, and isolated several *Thermococcus* species. She also tried to isolate the first viruses from these archaea, using methods established by Zillig. She and Forterre discovered no viruses, but they did find that *Thermococcus* strains produced a vast amount of membrane vesicles from cells containing plasmid DNA. Since then, large quantities of membrane vesicles have been found, particularly in ocean water, and produced by eukaryotes and bacteria. They are thought to contribute to DNA transfer between species, so they may have a role in evolution.

Ever since Forterre read Woese's work on the identification of the archaea and its implications for the tree of life, he has wondered about a last universal common ancestor of all life. His book walks the reader through his fascinating journey to understand how life evolved. Today, Forterre believes that viruses played a vital part. *Microbes from Hell*, in interweaving a scientific life with the grand discovery of the archaea, is a wonderful homage to this exciting field, which continues to challenge our view of life's origins. ■

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