cant differences in composition between the terrestrial mantle and the Moon.

Cattermole and Greeley both provide comprehensive lists of references; surprising omissions in Greeley's bibliography are Jay Melosh's standard text *Impact Cratering: A Geologic Process* (Oxford University Press, 1989) and Don Wilhelm's marvellous account of lunar stratigraphy (US Geological Survey Professional Paper 1348, 1986).

The overall effect is stunning, however. What student of W. M. Davis, Charles Cotton or Bill Thornbury would have imagined having the landscapes of a multitude of new worlds to investigate? The differences among the planets and satellites bring another sobering message: if we make this planet uninhabitable, or if doom threatens from an asteroid or cometary impact, only Mars might serve as a refuge. It would be slightly more comfortable, assuming an oxygen supply, than Antarctica, but with the blizzards replaced by global dust storms. □

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Knowing the technological future

David Edgerton

Exploring the Black Box: Technology, Economics and History. By Nathan Rosenberg. *Cambridge University Press: 1994. Pp. 274. £40, $54.95.*

THE generation of new scientific and technological ideas and artefacts is, in the late twentieth century, a huge industry in its own right. It absorbs two per cent and more of the gross domestic product of the richest industrial countries. This industry, like so many others, has attracted the attention of economists and historians and, because so much of it is publicly financed, students of government too. Indeed, the innovation industry has been regarded as more important, and more characteristic of the modern age, than any other. After all, for Alfred Whitehead, the greatest invention of the nineteenth century had been invention itself. For Joseph Schumpeter, what he saw (in the interwar years) as the 'routinization' of innovation made obsolete the key historical figure of the entrepreneur and paved the way for socialism (of a sort). For others, such as J. D. Bernal, planned invention and development required socialism, and promised abundance and social harmony.

If sulphuric acid production was once a proxy for the performance of a nation, now it is spending on research and development (R&D). "More R&D" has been the cry of scientists and engineers for many decades. Economists, however, have long despaired at such naivety: they argue that invention and innovation are just one source of growth, and that both are themselves shaped by economic forces. It is simply not the case, they say, that the performance of national economies is determined by R&D spending. On the other hand, economists found that their own models of economic growth accounted for only a small fraction of actual growth, and many were tempted to attribute the 'residual' amount to technological progress. Nevertheless, historical cost–benefit analyses regularly showed that single technologies, such as steam engines in the Industrial Revolution or railways in the late-nineteenth-century United States, did not have the major economic impact loosely attributed to them. Coming to grips with the origins, nature and significance of technological change has proved to be remarkably difficult.

Over the years, the writings of Nathan Rosenberg on technological innovation have provided an invaluable guide to these often intractable issues. They have been rightly applauded not only for their rare lucidity but also for their freshness and suggestiveness. Rosenberg is a master of the well-crafted thought-provoking essay. Indeed, he is best known through two previous collections of his essays, *Perspectives on Technology* (1976) and *Inside the Black Box* (1982). This latest collection is very much in the same tradition and will undoubtedly be widely read. If you read nothing else on technological innovation, you will not go wrong by reading Rosenberg. One of the great virtues of his work is that it is easily accessible to the general reader. Furthermore, Rosenberg's enthusiasms and interests are good reflections of the interests of economists of technical change, and of other students of science and technology.

Rosenberg, often writing with a colleague, has also made a reputation as a quality controller of the literature on innovation. This volume contains an excellent example. In a paper with Claudio Frischtak he demolishes the view, widely canvassed in the early 1980s, that there have been long swings of economic activity powered by clusters of key technological innovations. They doubt the existence of these long waves, and then go on to argue that proponents of technological long waves did not put forward an adequate mechanism for the generation of long waves by innovations. They go on to ask, however, what those mechanisms might be. Proponents of the long-wave view, they argue, simply did not recognize the complexities of the issues involved.

In common with many students of technological change, Rosenberg has been critical of the unrealistic, and often unhelpful, assumptions of neo-classical economists about technology. One way in which he has furthered this argument is by producing essays on past economic analysts of technological change. He wrote an important essay on Karl Marx and the economic role of science in the 1970s, and in this collection takes on the cases of two other much cited but often misunderstood students of technology: Babbage and Schumpeter.

Charles Babbage probably owes his contemporary fame to the ubiquity of the computer and the exaggerated role he has been given as its creator. But readers of Marx would know Babbage, along with the chemist Andrew Ure, from the footnotes to *Das Kapital*. Marx relied on their analyses of industrial technology and the division of labour in his chapter on modern industry. Rosenberg elegantly describes Babbage's innovative thinking on the benefits to employers of the division of labour and how Babbage's now famous calculating engines were intended to replace human 'computers'. His essay on the Austrian economist Joseph Schumpeter, who spent the last years of his professional life at Harvard, is also a model analysis of the works of a complex and rich thinker. Both pieces are excellent introductions to the key work of these seminal men.

Rosenberg stresses the centrality of uncertainty in technical change: in policy terms he argues for the need to follow many possible technical paths, the need for diversity in research and the need to plan for flexibility in future. He argues also for the importance of recognizing the significance of the path-dependence of large-scale technical change. Forecasting of the technological future, he shows, has been notoriously poor, and, perhaps most refreshingly of all, he studies technical change in industries ignored by high-technology enthusiasts; in this volume, large-scale chemical processing and the wood industry. His work stands as a warning, too often unheeded, to those who believe that they can know the technological future, and who would confine temporarily unfashionable industries to the dustbin of history. One of Rosenberg's great insights is to show that despite the futurist orientation of studies of technological innovation, there is a great deal to learn from the economic history of technology: after all, we have lived in technological societies for a very long time. □

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