

should also be incorporated into models of the chemistry inside these diffuse clouds. ■

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1. Knauth, D. C., Andersson, B.-G., McCandless, S. R. & Moos, H. W. *Nature* **429**, 636–638 (2004).
2. Viala, Y. P. *Astron. Astrophys. Suppl.* **64**, 391–437 (1986).
3. Womack, M., Ziurys, L. M. & Wyckoff, S. *Astrophys. J.* **393**, 188–192 (1992).

4. Bergin, E. A., Langer, W. D. & Goldsmith, P. F. *Astrophys. J.* **441**, 222–243 (1995).
5. Black, J. H. & Dalgarno, A. *Astrophys. J. Suppl.* **34**, 405–423 (1977).
6. Lutz, B. L., Owen, T. & Snow, T. P. *Astrophys. J.* **227**, 159–162 (1979).
7. van Dishoeck, E. F. & Black, J. H. *Astrophys. J.* **340**, 273–297 (1989).
8. Millar, T. J. *Mon. Not. R. Astron. Soc.* **199**, 309–319 (1982).
9. Ehrenfreund, P. & Charnley, S. B. *Annu. Rev. Astron. Astrophys.* **38**, 427–483 (2000).
10. Crutcher, R. M. & Watson, W. D. *Astrophys. J.* **209**, 778–781 (1976).
11. Meyer, D. M. & Roth, K. C. *Astrophys. J. Lett.* **376**, L49–L52 (1991).

Economics

The wealth of nations

Jared Diamond

A country's affluence depends partly on its institutions. Geographic and other factors yield a fuller explanation, illuminate the origins of 'good' institutions, and suggest targets for foreign aid.

Why are per capita income and gross national product more than 100 times higher in some countries than in others? Why are resource-poor Iceland and Luxembourg among the ten richest countries, while resource-rich Bolivia and Nigeria are among the poorest? This question is of practical as well as academic interest: if we knew the answers, perhaps poor countries could use them to achieve wealth. But the question is controversial and complicated, as a burst of publications attests^{1–9}.

The usual view is that differences in national wealth arise from differences in the accumulation of physical and social capital and in the adoption of new technology, due in turn to differences in the quality of political and economic institutions^{10–14}. Rich countries are rich because they have 'good' institutions promoting investment and accumulation of wealth. A conclusion from this view, embraced by many aid programmes, is that the best way to help poor countries is to assist them in developing good institutions — such as the rule of law, honest, efficient government, impartial enforcement of contracts, unimpeded flow of capital and goods across international borders, and protection of investors' property. The most convincing support for this view comes from four pairs of neighbouring countries sharing the same environment, one of them rich and with 'good' institutions, the other poor and with 'bad' institutions: South and North Korea, the former West and East Germany, Israel and its neighbours, and the Dominican Republic and Haiti.

This answer undoubtedly contains much truth. No one considers it wrong, and many commentators consider it a full answer (and disagree with the studies discussed below). However, increasing numbers of economists find it incomplete, for two reasons. First, the answer merely notes national differences in institutional quality, and says nothing about



Figure 1 Rich and poor: skyscrapers and a shanty town, icons of contrasting conditions among the world's nations.

their origin. Why did Luxembourg, of all countries, end up with good institutions, whereas Nigeria didn't? Second, the answer neglects the non-institutional factors.

As regards origins, good institutions don't arise at random around the world.

Instead, they are outcomes of a long history shaped by geography, which helps to explain why Luxembourg has them but Nigeria doesn't. The origins of complex institutions are linked inextricably with the origins of states, which unfolded over thousands of years as by-products of sedentary, populous agricultural societies. These arose independently in only a few areas of the world endowed with many domesticable wild plant and animal species, beginning around 8500 BC in the Fertile Crescent of the Middle East¹⁵. In particular, state societies gradually evolved national loyalty instead of clan loyalty, deep experience of centralized government, pools of trained administrators and educated, literate citizens, and enforcement of social norms through government-administered laws rather than through individuals taking matters into their own hands. It proves difficult to telescope those developments of millennia into a generation through imitation and foreign aid.

Two studies^{1,2} by economists demonstrate this relevance of historical geography to institutional origins. In one study, Hibbs and Olsson¹ compared 112 nations' per capita wealth with the time since the local transition from hunting/gathering to agriculture. Two conclusions emerged: the larger the local biogeographic endowment of domesticable, large wild mammals and large-seeded wild cereals, the earlier was that transition locally; and the earlier that local transition, the richer is the country today. Part of the explanation is that some (but not all) countries with a long history of complex agricultural societies ended up with good institutions: geography and biogeography account for 40% of the explained variance in institutional quality.

In the other study², Bockstette *et al.* examined the growth rate of per capita wealth in the past 50 years, instead of current wealth itself. It turned out that countries with a long history of state societies have recently tended to enjoy high growth: countries that 50 years ago were still poor but had already developed complex institutions caught up quickly, once they added advanced technology to their institutional advantages.

For example, around 1950, when South Korea, Ghana and the Philippines were equally poor, most economists predicted that resource-rich Ghana and the Philippines were on the verge of wealth, whereas South Korea was doomed to remain mired in poverty. The result, of course, has been the opposite, because for 1,300 years South Korea has formed half of a unified, literate kingdom, and was strongly influenced by neighbouring China (one of the world's two oldest agricultural civilizations) long before that, whereas Ghana and the Philippines were exposed to rudimentary state government only within the past few centuries. As another example, Iceland, until a century ago Europe's poorest

country, is now among the world's ten richest despite its modest resources, while resource-rich Zambia is still poor. But Zambia acquired colonial state government barely a century ago, whereas Iceland has been a literate state for 1,100 years.

Besides those historical legacies, geography may also contribute to wealth through its effects on public health, agricultural productivity and transport costs^{3,4}. The first two of those factors penalize tropical countries, and the last penalizes land-locked countries.

As regards public health, tropical countries tend to carry much heavier disease burdens than do those of temperate zones, because parasites and disease vectors thrive all year round in the tropics but not in temperate climates. Disease is obviously bad for economies: workers who have spent years training have lower productivity and fewer years to contribute to the labour force than they otherwise would; high child mortality drives parents to bear many children in the hope that some will survive, so that frequent pregnancy or lactation makes women less able to join the work force; and health costs drain government budgets.

As for agricultural productivity, one might at first expect higher crop yields in year-round tropical climates than in temperate zones. But the reverse is true, for reasons that include parasites and crop pests.

Finally, transport costs by boat are lower than those over land — and hence lower for countries with a sea coast, or with big navigable rivers, than for land-locked countries without such rivers. That helps to keep countries such as Afghanistan, Bolivia, Chad, Laos, Mali and Zambia poor.

The burdens on health and agriculture explain why tropical countries are on average poorer than those of temperate regions, and why until recently the more tropical parts of the United States and Brazil were poorer than their temperate parts. Proof of the pudding comes from Southeast Asia's 'tiger' economies, which have achieved spectacular growth in the past half-century. Hong Kong, Malaysia, Mauritius (in the Indian Ocean), Singapore, Taiwan and Thailand became rich precisely by recognizing their tropical penalties, and by investing heavily in overcoming them through public-health measures, family planning, and developing economic sectors other than agriculture (Fig. 1).

Moving beyond geography, there are at least three non-geographic explanations for differing national wealth: the paradoxical curse of natural resources, reversals of fortune after colonization, and environmental damage. Taking first the resource curse, a common-sense prediction is for countries rich in natural resources, such as minerals, oil and tropical hardwoods, to be wealthier than countries not so endowed. In fact, countries deriving much of their income or foreign exchange from natural resources

— such as the Congo and Nigeria — are paradoxically poor^{5–7}. Among the suggested reasons for this are that dependence on natural resources promotes civil wars (with people of resource-rich provinces seceding to control their local resources); it creates temptations for corruption; and it raises prices and wages, thereby stunting the growth of manufacturing and other economic sectors.

Acemoglu *et al.*^{8,9} used the term "reversal of fortune" to explain differing economic changes among non-European countries colonized by European states in the past 500 years. The areas whose pre-colonial native societies had been richest (for example, Bolivia and Peru as parts of the Inca Empire, Mexico as the centre of the Aztec Empire, and India) are now poorer than pre-colonially poor areas such as Australia, Canada, New Zealand and the United States. Acemoglu *et al.* note, by way of interpretation, that areas that were formerly rich and densely populated but afflicted with tropical diseases were settled by few European colonists, who siphoned wealth from local people by exploitative institutions that today are bad for their economies as independent countries. In contrast, poorer areas where Europeans did not suffer high disease mortality did attract European settlers, who introduced institutions like those in their mother countries and more conducive to development.

Finally, a moment's reflection will suggest an objection to the idea that early agricultural origins lead to wealth^{1,2}. By that argument, the world's richest countries should now be those where agriculture arose earliest: Iraq, Iran and Syria. In fact, all three are poor

today, and would be even poorer were it not for oil. What happened? Their inhabitants had the misfortune to be living in fragile environments with low rainfall or high sub-surface salt, which over millennia became damaged by deforestation, overgrazing, soil erosion and salinization. Those countries, too, experienced a reversal of fortune, but one due to environmental deterioration rather than colonial history¹⁶. Hence, a message from the studies described here is that aid donors should invest not only in institutions but also in public health, family planning and environmental protection. ■

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- Hibbs, D. A. Jr & Olsson, O. *Proc. Natl Acad. Sci. USA* **101**, 3715–3720 (2004).
- Bockstette, V., Chanda, A. & Putterman, L. *J. Econ. Growth* **7**, 347–369 (2002).
- Sachs, J. D. *et al. Sci. Am.* **284**, 62–67 (2001).
- Sachs, J. D. & Malaney, P. *Nature* **415**, 680–685 (2002).
- Sachs, J. D. & Warner, A. M. *J. Afr. Economies* **6**, 335–376 (1997).
- Sachs, J. D. & Warner, A. M. *Eur. Econ. Rev.* **45**, 827–838 (2001).
- Ross, M. *World Politics* **53**, 325–361 (2001).
- Acemoglu, D., Johnson, S. & Robinson, J. A. *Am. Econ. Rev.* **1**, 1369–1401 (2001).
- Acemoglu, D., Johnson, S. & Robinson, J. A. *Q. J. Econ.* **117**, 1231–1294 (2002).
- Smith, A. *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776; reprinted by Penguin, London, 1999).
- North, D. C. & Thomas, R. P. *The Rise of the Western World: A New Economic History* (Cambridge Univ. Press, 1973).
- Hall, R. E. & Jones, C. R. *Q. J. Econ.* **114**, 83–116 (1999).
- Knack, S. & Keefer, P. *Econ. Politics* **7**, 207–227 (1995).
- Easterly, R. & Levine, R. *J. Monet. Econ.* **50**, 3–39 (2003).
- Diamond, J. *Guns, Germs, and Steel: The Fates of Human Societies* (Norton, New York, 1997).
- Redman, C. O. *Human Impacts on Ancient Environments* (Univ. Arizona Press, Tucson, 1999).

Nanophysics

A step up to self-assembly

Kristen Fichthorn and Matthias Scheffler

Powerful computer simulations have resolved the mechanism for the nanoscale assembly of the 'hut'-like clusters that form after a few layers of atoms have been deposited on certain solid surfaces.

From the beautiful snowflakes that form from a random aggregation of water molecules, to the creation of a living organism, nature has found such efficient means of self-assembly that, in contrast, human techniques often seem crude. Even in our most impressive technologies for fabricating microstructures on surfaces — such as the lithographic techniques used to create integrated circuits — human efforts still seem like chiselling patterns out of stone. At the nanometre scale, the resolution that can be achieved using lithography is reaching its limit, and a new set of tools is needed. By better understanding nature's methods for assembly on solid surfaces, involving diffusion, nucleation and growth, it might be

possible to orchestrate these phenomena such that a complete computer chip consisting of several billion transistors could assemble itself, like a complex biological organism. Indeed, for nanotechnology to become affordable, nanostructures will have to build themselves; normal manufacturing methods will be useless. The laws of physics do not preclude this possibility, but our present understanding of surface physics is still too shallow to achieve such complex self-organization and assembly.

Zhu and colleagues¹, writing in *Physical Review Letters*, have quantified one of nature's mechanisms for creating nanometre-scale objects when atoms are deposited and grow into thin films on a solid surface of the same