



Mother Nature Necessitates Invention

And Technology Buoy Industry

by R. David Simpson

The United States remains competitive in world resource markets, despite geological disadvantages and a relatively long history of depletion. American ease with innovation helps explain why.

A generation ago, some prognosticators warned that Americans should brace themselves for an era of scarcity. The natural resources we depended on for food, clothing, shelter, and energy were dwindling, they claimed. But after years of resource use, the specter of scarcity remains just that. In fact, it has faded somewhat. Natural resources are neither scarce nor expensive and their price tags have declined—as much as 40 percent in the past forty years.

Prices have declined because the costs of producing natural resources have dropped. Costs have dropped because improvements in technology have more than offset the effects of depletion. Technological innovation, then, is something of a savior for America's consumers and natural resource producers, helping to make the latter strong competitors on the international market. Even copper mining is flourishing, though it seemed doomed as an American enterprise not long ago.

How exactly has technology controlled costs? With support from the Alfred P. Sloan Foundation, researchers at RFF have been exploring this question as part of a study of productivity change in four U.S. natural resource industries: coal mining, oil and gas exploration, copper mining, and forestry. In conducting the research, we performed individual case studies first and then a statistical analysis of productivity trends in the four industries. Thus we took both “bottom up” and “top down” approaches.

The record of productivity growth in U.S. natural resource industries is mixed, and does not lend itself to easy interpretation. Changes in market conditions

and regulation in the 1970s apparently had some temporary negative effects on productivity. Superimposed on these temporary phenomena may be the effects of the gradual depletion of more easily accessible reserves. There is, however, a long-run trend working in the opposite direction: the introduction and adoption of improved production technologies have offset the effects of depletion. One can never be sure that such a trend will continue. Our findings published in *Productivity Change in Natural Resource Industries* identify three factors that explain how and why technology has kept natural resources relatively cheap and plentiful in the United States, however, and suggest that the same factors will continue to be important in the future.

Origins of Innovation

First of all, necessity does appear to be the mother of invention. Were it not for new technologies, extraction costs would go up as the most accessible reserves went down. The viability of companies or even whole industries depends on continuing technological progress.

Second, new inventions are rarely the results of immaculate conceptions. If necessity is their mother, then the general state of technology might be said to be their father, determining the set of innovations possible. Furthermore, breakthroughs come at the end of what can be a long gestation period that often involves cross-fertilization. New machinery and processes are rarely truly novel, consisting rather of recombinations of existing technologies.

Third, a nation's legal, political, and social institutions play a crucial role in encouraging solutions to be conceived in the first place and then husbanded through to maturity. How well a society nurtures invention makes a big difference in how much of it occurs. The United States, for example, offers a much more "innovation-friendly" environment than many of its competitors.

Winnowing Waste

Perhaps the best example we found of necessity mothering invention is something called the solvent extraction-electrowinning (Sx-Ew) process in copper mining. In the 1970s, U.S. mining companies had to reduce costs if they were to survive competition from foreign suppliers. Developing the Sx-Ew technology was an important component of the latter strategy. It enabled copper companies to "mine" the waste streams from their earlier operations; now they could extract enough copper from mine tailings to make them viable ore sources.

Just how much American copper companies have relied on the more intensive working of existing mines is striking. Annual U.S. copper production increased by more than 40 percent between the 1970s and 1990s. But new mines were few and only accounted for some 3 percent of U.S. copper production in 1995.

Similarly, a dwindling supply of trees has driven innovation in the forestry industry. Earlier improvements in harvesting technology made it possible to eliminate large swathes of forest closest to centers of population and industry. Once the most easily accessible forests were gone, setting out for increasingly rare and inaccessible virgin forest was not an attractive option. Not only are these remote areas costly to harvest, they are increasingly in demand as preserves for recreation and biodiversity conservation. Often it has become more profitable to replant and manage previously harvested areas instead. More and more, trees are being grown on plantations and treated like crops. They are being harvested in areas best suited for forestry and not simply reproduced where they stood in the past.

Increments and Complements

Among our case studies, use of three-dimensional seismology in petroleum exploration and development

Impacts on Innovation

Most people would agree that new types of machines are innovations. But what about new management practices? Government regulations? Changes in labor relations? They, too, are agents of transformation. Even when such developments do not amount to what might be considered innovations, however, they can have an impact on productivity change. Sometimes they drive innovation more than depletion does. Competition is one example.

probably best illustrates how incremental progress has enhanced the applicability of a new technology. The way in which the technique is used today likewise shows how innovation depends on the technologies generally available in the economy, as well as those being employed in particular industries. The principles underlying 3D seismology have been known for close to a century, but its practical application had to await development of high-speed parallel computing. Absent the ability to compile and interpret extremely large amounts of data, the technique, which involves the use of sound waves to map out the shape and location of underground geological formations, was far too slow and costly to apply in practice.

Today, 3D seismology is widely used in conjunction with directional drilling and in deepwater extraction operations. These three technologies are highly complementary. Having precise information about reservoir shape and location is less valuable if the technology is not available to enter a reserve from the optimal angle. This entry is precisely what directional drilling allows. Similarly, deepwater drilling is an extremely expensive process. It would not be economical were it not possible to obtain surveys sufficiently accurate to ensure a high probability of success, which 3D seismology allows.

Complementary innovations have had reinforcing and enabling effects in all of the industries that we have studied. Plantation forests, which are themselves innovations, are profiting from biotechnological breakthroughs and from techniques first developed for agricultural crops and animal husbandry. As forestland is more and more at a premium, investments in genet-

ically improved trees are paying off. Selective breeding for commercial attributes like superior growth and quality is becoming more common. The adverse consequences of selection for such attributes can be offset by the use of pesticides and fertilizers, as well as irrigation and preharvest thinning.

In the coal industry, the advantage of “longwall” mining to more effectively exploit thinner and deeper seams increased in lockstep with improvements in the power and positioning technologies for deploying it. In fact, the advent of ever larger and more powerful machinery—including trucks the size of small buildings—has enhanced coal productivity overall. These developments depended on a host of mechanical improvements.

Of course, sometimes an industry’s technology does advance piecemeal. Although the history of oil and gas exploration is an incremental one built on adaptation of outside technologies, it is also episodic: That is, first one technology was developed that could identify one type of deposit; deposits of that type were discovered and exploited. Then a second technology was developed to identify a second type of deposit; deposits of the second type were discovered and exploited; and so on.

But close inspection of industry histories suggests that episodic evolution is the exception that proves the rule. The clear evidence of all the case studies is that even major innovations are accompanied by ancillary developments that enhance their efficiency and broaden their applicability.

A Culture of Innovation

The pressure of circumstances and the spillover benefits from complementary technologies do not provide a complete explanation of how and why innovation occurs. As seen in the case studies as well as in general data on world economic development, those nations and firms that pioneered new technologies in one period are likely to do so in the next. To some extent, this tendency might be seen as a consequence of the factors already cited. If depletion induces innovation, further depletion may induce further innovation. And if the existence of one generation of technology creates conditions for the birth of another, the firms and countries that produce the first generation may be better positioned to produce the second. Innovations do get diffused throughout the world, but

Competition

By and large, the case studies support the view that competition begets innovation. The study of coal provides ample evidence that a period in which regulatory considerations generated greater competition between producers was also one in which tremendous technological strides were made.

Being denied protection from foreign competition in the 1970s appears to have strengthened the U.S. copper industry. Those firms that survived were forced to innovate. As a result, the U.S. industry is arguably more competitive now than many of its foreign rivals, who, despite their advantage of richer reserves, have not made the same investments in modernization.

In the 1980s, the U.S. petroleum industry faced a squeeze between competition from foreign producers and the upward pressure exerted on costs by the depletion of easily accessible domestic reserves. This double bind forced development of techniques to exploit known reserves at competitive costs.

technological leadership tends to persist.

Why do some countries that enjoy an advantage with respect to their endowments of natural resources fail to press that advantage by investment? And why, on the other hand, do some nations with relatively few resources invest in extraction and grow rich? Simple theory predicts that the return to capital investment ought to be higher in areas in which capital stock is low compared with plentiful labor, resource reserves, and other factors of production. The

Public Funding

Government ownership of resource stocks might be expected to reduce incentives for innovation. Nonetheless, public support for research and development has proven important. The solvent extraction-electrowinning process now used in copper mining was first employed in mining uranium for military purposes. Byproducts of publicly funded research related to outer space include global positioning systems used in the coal industry to make extraction and movement of coal more efficient, and satellite communications used to transfer seismological data from petroleum exploration. Public funding has also helped advance diffusion. Research at the U.S. Bureau of Mines helped foster the introduction into this country of longwall mining technologies pioneered in Britain and Germany.

basis for this theory is that investment would flow from the wealthier to the poorer nations of the world. In fact, it appears that the opposite is often true. Japan, for example, has relatively few natural resources but receives a great deal of capital investment, while many richly endowed African nations receive very little.

A great many explanations for this apparent paradox have been proposed. One common notion is that capital investment—and, in particular, investment in high-technology equipment—either creates or attests to conditions where further investment in high-technology equipment is profitable.

We can only point out that improving technologies incrementally, borrowing related technologies, and recombining existing ones to generate innovations are facilitated by corporate ties and physical proximity. Even in the absence of these factors, relative openness with respect to information sharing, as may occur among firms within and among advanced industrial countries, seems conducive to innovation.

A more basic consideration yet is that innovators, if they are to have an incentive to innovate, must have some confidence that they are going to enjoy the rewards of success. Many regions blessed with abundant resources lack what may be termed the political, social, and cultural prerequisites for world-class production. It would be a good thing for both humanitarian and pragmatic reasons if developing nations could quickly acquire these prerequisites.

To the extent that they do not, however, we can anticipate that U.S. natural resource industries will remain competitive in world resource markets despite the fact that geology and a longer history of depletion would seem to place them at a cost disadvantage. It is true that the scale of U.S. production has, in some instances, declined in absolute terms or relative to world production. The fact remains, however, that U.S. firms are able to produce at costs that make them competitive with foreign rivals. This fact must be ascribed to an ability to develop and adopt new technologies more readily than many of its competitors.

Like the United States, those firms and nations that demonstrate a persistent commitment to innovation

A New Era of Scarcity?

With gasoline prices near historical lows one might not expect it, but some researchers are suggesting that a new era of oil shortages is just around the corner. As Richard Kerr has reported (*Science*, 21 August 1998, pp. 1128–1131) these researchers predict that the end of cheap oil is coming soon. They argue that since the most easily accessible petroleum reserves are near exhaustion, costs of production will begin to rise.

RFF researchers Joel Darmstadter and Michael Toman challenge this assertion, however, as indicated in their letter of response (*Science*, 2 October 1998, pp. 47–48). The innovations documented in *Productivity Change in Natural Resource Industries* provide examples of how the petroleum industry might again deal with difficult circumstances. Moreover, the issue is not so much the physical depletion of petroleum reserves as society's demand for them. Just as more fuel-efficient cars were built in response to the energy crisis of the 1970s, we might again successfully substitute efficiency for quantity of energy use and weather future shortages.

and the development and use of new technologies are likely to remain profitable even if their new technologies can be copied in a matter of years or even months. The reason is that successful research and development have as much to do with continuing experimentation as they do with specific breakthroughs. Those who are willing to experiment—and who are blessed by experience, temperament, and, perhaps, cultural support—may remain industry leaders for longer periods than their resource endowments suggest.

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