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The Ingenuity Gap: Can Poor Countries Adapt to Resource Scarcity?

THOMAS HOMER-DIXON

THE EARTH'S CURRENT human population of 5.7 billion is growing by 1.6 percent a year. On a global average, real economic product per capita is also growing at 1.5 percent a year. These increases combine to boost the globe's total economic product by about 3 percent annually. Extrapolation therefore suggests that today's global product of US$25 trillion will exceed $50 trillion in today's dollars by 2020.

A large portion of this doubling of world product, should it occur, will be achieved through increased consumption of the planet's natural resources, including nonrenewables like petroleum and ores, and renewables like cropland, forests, fresh water, and fisheries. Already, we are causing major changes in these resources: "transformed, managed, and utilized ecosystems constitute about half of the ice-free earth; human-mobilized material and energy flows rival those of nature" (Kates, Turner, and Clark 1990: 13). Such changes are certain to grow in magnitude because of the rapidly increasing scale of economic activity.

Increased resource consumption can cause resource scarcities, and scarcities impose costs on societies. But experts debate the severity of future scarcities and human capacity to adapt to them. There are three main positions in this debate (see, e.g., Barbier 1989; Matthaei 1984). Neo-Malthusians, who are often biologists or ecologists, claim that finite natural resources place strict limits on the growth of human population and consumption; if these limits are exceeded, poverty and social breakdown result. Many neoclassical economists, in contrast, say that there need be few, if any, strict limits to human population, consumption, and prosperity.[1] Properly functioning economic institutions, especially markets, provide incentives to encourage conservation, resource substitution, development of new stores of scarce resources, and technological innovation.[2] Finally, analysts whom I call "distributionists" acknowledge that there may be resource limits to human population growth, but for them the real problem is the maldistribution of resources and wealth. Poverty and inequality, in their view, are the cause, not the consequence, of high population growth rates and practices that deplete resources (see, e.g., Lappé and Collins 1977; Blaikie 1985; Boyce 1987).

This three-cornered debate has become sterile. In most popular accounts, the protagonists are arch-optimists like Julian Simon, who believe that scarcities pose no bounds to human prosperity, and arch-pessimists like Paul Ehrlich, who argue that the human population is already far too large for the Earth's resource base (Simon 1981; Simon and Kahn 1984; Ehrlich and Ehrlich 1991). Although these bitter exchanges accomplish little, the paradigms underpinning the three positions have great influence. In particular, the neoclassical view guides the responses of the World Bank and other multilateral development agencies to resource problems in poor countries, and it informs commentary in influential business-oriented newspapers, magazines, and books.

Neoclassical economists stress the extraordinary ability of human beings to surmount scarcity and improve their lot. The dominant trend over the past two centuries, they point out, has not been rising resource scarcity but increasing aggregate wealth. In other words, they note that most important resources have become less scarce, at least in economic terms. By this view, if we want to judge whether human beings can prosper in the future, we should ask two questions: What factors determine wealth production? And will these factors allow human beings to surmount scarcities in the future as they have often done in the past?

For decades, economists have heatedly discussed the first question. In this article I build on insights derived, in part, from the research of an increasingly influential group of theorists in this discussion. Their work is variously called "new economic growth theory" or "endogenous growth theory" (see, e.g., Romer 1994; Helpman 1992). They argue that ideas, as embodied in new technologies, are a factor of economic production in addition to capital, labor, and land. Ideas have independent productive power. They also argue that productive ideas are not exogenously given to economic actors but are, at least in part, endogenously generated by the actors and the economic system.

In this article I adopt and extend both these arguments. I contend that technological ideas are not the only productive ideas; just as important are ideas about social organization, especially about reforming and building institutions. And I argue that the generation and dissemination of productive ideas is endogenous not just to the economic system but also to the broader social system that includes a society's politics and culture.

My focus here, therefore, is on the generation of ideas, or what I call "ingenuity," in response to resource scarcity. In its simplest form, the central question I ask is: Can humans be smart enough at the right times and places—can they generate and disseminate enough ingenuity—to keep scarcity from negatively affecting their wellbeing? In answer, I first discuss what I mean by ingenuity. I then identify some factors that affect the requirement for and the supply of ingenuity. In some societies, I argue, resource scarcity can simultaneously increase the requirement and impede supply, producing an "ingenuity gap" that may have critical consequences for adaptation and, in turn, social stability.

I do not have precise measures for ingenuity; the argument here is heuristic and illuminative, not quantitative. But I believe researchers can eventually operationalize the key variables and specify the general shapes of the key functions. In time, on the basis of measurable data, we should be able to predict when and where ingenuity gaps will appear.

The nature and role of ingenuity

For many decades, economists have been arguing about the role of ideas, innovation, and ingenuity in economic growth. For example, Robert Solow (1957) examined the contributions of physical capital and labor to growth, and he showed that a sizable residual could not be explained by the accumulation of these factors of production. He attributed the difference to the contribution of technology.

Economists now generally agree that technology should be included in any explanation of economic production. But they still dispute whether the innovative ideas embodied in technology have an independent productive role that would explain the "Solow residual" or whether the contribution of ideas can be subsumed under growth in conventional factors of production, particularly growth in human capital (that is, a knowledgeable and productive labor force). Some economists claim to have largely eliminated the Solow residual by carefully accounting for changes in the quality and quantity of labor and capital and for economies of scale (see the survey in Maddison 1987). Others, who are typically called "new economic growth theorists," argue otherwise.

Although the debate has not been resolved, Paul Romer, one of the leaders of the new economic growth school, has made several points that shift the balance in favor of his perspective. "Ideas," Romer writes, "are the instructions that let us combine limited physical resources in arrangements that are ever more valuable" (1993b: 64). The most important thing about ideas, he emphasizes, is that they cannot be reduced to human capital, as economists who claim to have eliminated the Solow residual would have us believe. This is because ideas are nonrival, whereas human capital is rival. A good is nonrival if its use by one actor does not limit its use by another.[3] While an idea has this characteristic, since it exists independently of its producer or user and can be used by many people at the same time, human capital does not: the use of a particular pool of human capital by one firm or organization restricts its use by others. Romer (1990: S74–S75) makes this point by referring to ideas as "designs" (such as chemical formulas or principles of engineering):

> A design differs in a crucial way from a piece of human capital such as the ability to add. The design is nonrival but the ability to add is not. The difference arises because the ability to add is inherently tied to a physical object (a human body) whereas the design is not. The ability to add is rivalrous because the person who possesses the ability cannot be in more than one place at the same time; nor can this person solve many problems at once.

A key consequence of the nonrival nature of ideas is that, although they may be expensive to produce the first time, they can then be infinitely replicated and accumulated at very low cost.

> Nonrival goods can be accumulated without bound on a per capita basis, whereas a piece of human capital such as the ability to add cannot. Each person has only a finite number of years that can be spent acquiring skills. When this person dies, the skills are lost, but any nonrival good that this person produces—a scientific law; a principle of mechanical, electrical, or chemical engineering; a mathematical result; software; a patent; a mechanical drawing; or a blueprint—lives on after the person is gone. (1990: S75)

It is tempting, Romer notes, to aggregate ideas and human capital because they are "so closely related as inputs and outputs." Nonetheless, they should be treated separately. "Ideas are," he goes on, "the critical input in the production of more valuable human and nonhuman capital. But human capital is also the most important input in the production of new ideas." While physical capital—for example computers, telephones, and laboratory equipment—often aids human capital, "a trained person is still the key input in the process of trial and error, experimentation, guessing, hypothesis formation, and articulation that ultimately generates a valuable new idea that could be communicated to others and used by them" (1993b: 71).

The new economic growth theorists argue cogently that ideas have intrinsic productive power and account for a significant fraction of economic growth. These arguments are an important starting point for understanding social and economic adaptation to scarcity.

What is ingenuity?

The central concept I introduce in this article is "ingenuity."[4] By ingenuity I mean *ideas* applied to solve practical social and technical problems. This definition is more subtle than it first appears. Ingenuity, as used here, is explicitly narrower than "ideas" per se, since it refers only to ideas used to solve practical problems, whereas many if not most ideas are not used in this way.[5] Yet it is broader than "innovation," since innovation implies novelty; and, although ingenuity does not exclude novelty, practical ideas do not have to be novel to be classified here as ingenuity.

Whether an idea can be classified as ingenuity is not, by the above definition, a function of the success of the solutions it produces; thus, on occasion, a solution that uses more ingenuity—that uses, in other words, more ideas—might not work as well as a solution that uses less ingenuity. Moreover, ingenuity, as I use the term here, does not convey a judgment about the intrinsic quality or productivity of ideas. An increase in the ingenuity supplied by a society means simply an increase in the number of ideas it applies to its practical problems, not an increase in the quality of the ideas. This stipulation means that my concept of ingenuity does not capture some of the word's conventional meaning, because it is common for people to talk of an "ingenious idea," which implies that ingenuity is a qualitative property of the idea in question.

It would be helpful if we could eventually develop ways of distinguishing among ideas by their quality. Romer takes a first step by outlining a crude method for representing the information content of ideas.[6] But a means of distinguishing good ideas from ones that are not so good is not essential to my argument here. For simplicity, I focus only on the aggregate supply of ideas that a society applies to its practical problems.

Human ingenuity is usually so abundant that it hardly seems remarkable. It is evident in the practical solutions to the countless mundane difficulties we face as a species. On a daily basis, for instance, an average city receives an uninterrupted and seemingly coordinated supply of thousands of tons of food and fuel, tens of millions of liters of water, and hundreds of thousands of kilowatt hours of electricity. Huge quantities of wastes are removed; hospitals provide health services; knowledge is transmitted from adults to children in schools; police forces protect property and personal safety; and hundreds of committees and councils from the community to the city level deal with matters of governance. Of course, the amount of ingenuity needed to run such a system is not the same as the amount required to create it, because at any one time a vast array of routines and standard operating procedures guides people's actions. But the system and its countless elements are the products of the incremental accretion of human ingenuity. They have been created, over time, by millions of small ideas and a few big ones.

Ingenuity and scarcity

Drawing on the arguments of new economic growth theorists, I take ingenuity to be a factor of production, like labor, capital, and land (i.e., natural resources). Ingenuity often substitutes for labor and land by raising their productivity. For instance, the unprecedented growth in global agricultural output over the past 50 years was produced by a huge expansion in the stock of agricultural ideas embodied in people, institutions, and technologies, and, in contrast, "a modest expansion in the quantities of land and water devoted to agricultural production" (Crosson and Anderson 1993: 17). Ingenuity usually complements physical and human capital: thus investments in agricultural machinery and trained agricultural workers are invariably accompanied by increases in the local stock of ideas and instructions.

When we consider how ingenuity can alleviate resource scarcity, we must distinguish between technical and social ingenuity. People need technical ingenuity to address problems in the physical world and social ingenuity for problems in the social world. In industrial societies, resource scarcities are usually seen as technological challenges needing the keen attention of scientists and engineers (for example, to develop new plant varieties suitable for dry climates and eroded soils, and water and energy conservation technologies).

But the supply of this technical ingenuity depends on an adequate supply of social ingenuity at many levels of society. Social ingenuity is key to the creation, reform, and maintenance of public and semipublic goods such as markets, funding agencies, educational and research organizations, and effective government. If operating well, this system of institutions provides psychological and material incentives to technological entrepreneurs and innovators; it aids regular contact and communication among experts; and it channels resources preferentially to those endeavors with the greatest prospect of success. Social ingenuity is a precursor to technical ingenuity.[7] Society therefore needs ingenuity to get ingenuity, which means it is both an input to and output of the economic system.[8]

Social ingenuity is also key to adaptation strategies that do not involve new technologies. For instance, a society can adapt to a higher probability of food shortfalls arising from cropland scarcity by establishing lines of emergency credit and by making advance arrangements for transfers of food from food-producing to food-scarce regions. Such social ingenuity is often provided by competent bureaucrats as they design and implement policy and by astute political leaders as they bargain, create coalitions, and use various inducements to get policies enacted and institutions built. Of course, the ingenuity needed to adjust to resource scarcity is produced not only by people at the top of the social hierarchy: many of the ideas needed for successful adjustment are produced at the community and household levels as people learn, for example, how to reform local institutions to solve collective-action problems (see Ostrom 1990).

My use of the term ingenuity to cover ideas applied to both technical and social problems is a significant departure from new economic growth theory. Romer and other theorists in this school are mainly interested in technical ideas such as manufacturing techniques, industrial designs, and chemical formulas, especially those developed and applied within the firm. But Romer himself acknowledges that ideas about firm organization and the marketing and distribution of the firm's product have contributed importantly to economic growth,[9] and such ideas are analogous to the social ingenuity I discuss here.

The requirement for and the supply of ingenuity

I define the *requirement* for ingenuity in response to a given resource scarcity as the "constant-satisfaction requirement," which is the amount needed to compensate for any aggregate social disutility caused by the scarcity. It is, in other words, the minimum amount of ingenuity that a society needs to maintain its current aggregate level of satisfaction in spite of the scarcity.[10] The constant-satisfaction requirement is not an economic constraint in the real world; rather it is an arbitrary, analytical benchmark against which we can evaluate society's delivery of ingenuity.[11]

Many people who are optimistic about human ability to surmount resource scarcity implicitly use this constant-satisfaction benchmark: they argue that, with well-functioning economic institutions like markets, the level of satisfaction in a society over the medium and long run will not decrease despite occasional resource shortages. In other words, these optimists assume that ingenuity will be supplied abundantly and cheaply enough to alleviate any disutility arising from scarcity and that the society will demand at least this amount of ingenuity.

At any point in time, the constant-satisfaction requirement for ingenuity is partly a function of how far into the future we project this requirement. If we are concerned with maintaining constant satisfaction only into the near future, the present need for ingenuity might be quite limited. For example, if consumption currently exceeds the flow of a renewable resource, we might be able to tap the resource's underlying stock—and thus maintain our satisfaction for the short term—without radically changing our institutions, behavior, and technology. On the other hand, if we want to ensure constant satisfaction far into the future, our present need for ingenuity might be much higher; we might have to figure out *now* how to live within renewable resource flows.

I define the *supply* of ingenuity as the amount actually delivered by the economic and social system. This amount is determined by the price society is willing to pay for it and by numerous other variables, including availability of financial and intellectual capital, society's capacity to generate practical knowledge, and the willingness of society to undergo social and technological change. Ingenuity is supplied in two temporal stages.

The first is the generation of a potential solution to a particular problem; the second is the delivery and implementation of the potential solution.[12] Supply can be hindered by factors operating at either or both stages.

In the remainder of this article I argue that, as resource scarcity worsens, the social and technological problems faced by societies generally become more complex, unpredictable, and urgent. These changes tend to raise the constant-satisfaction requirement for ingenuity; in other words, greater scarcity increases the need for ingenuity to maintain aggregate social satisfaction. Greater scarcity also often boosts the supply of ingenuity by inducing changes in resource prices that, in turn, provide incentives to social and technological entrepreneurs. This increased supply can alleviate scarcity's severity and social impacts.

On the other hand, I also identify four factors that can restrict ingenuity's supply: market failure, social friction, shortages of capital, and constraints on science. I argue, therefore, that some societies will eventually experience a chronic "ingenuity gap" between their requirement for and their supply of ingenuity. This argument raises two empirical questions deserving future research: Are the negative influences on supply significant? And if so, are there identifiable circumstances in which these negative factors reduce the rate of growth of ingenuity below that of the constant-satisfaction requirement, thus creating an ingenuity gap?

My argument needs careful interpretation. First, the size of the ingenuity gap does not necessarily correlate with the extent of social disutility caused by scarcity. The amount of ingenuity needed to remedy a particular scarcity might be high, while the social disutility caused by the scarcity is low, or vice versa. However, a large ingenuity gap does indicate that the disutility—whatever its degree—will probably endure. Second, and more importantly, an adequate supply of ingenuity is a necessary but not sufficient condition for constant social satisfaction. The social distribution of the ingenuity supplied, how it is applied, and for what purpose it is applied also affect aggregate satisfaction. A full account of the social and economic role of ingenuity therefore requires separate models of ingenuity's distribution and use.

Some factors increasing the requirement for ingenuity

For many resources, both regionally and globally, population growth and increasing per capita resource consumption are causing a steady increase in the ratio of the consumption of the resource per unit of time to the total amount of the resource available.[13] This consumption/resource ratio is an approximate but useful measure of a resource's scarcity.[14]

A rise in this ratio for a given resource has a number of consequences. First, serious scarcities tend to affect larger regions. For example, the cod fishery has collapsed across much of the North Atlantic; water shortages have become chronic throughout the Middle East; and large areas of the interior and western regions of China are affected by erosion and loss of cropland.[15] Second, the ratio's increase often means a faster pace of resource depletion. Thus most of North America's conventional fossil oil has been consumed in a single lifetime; 20 percent of West Africa's forest was logged between 1980 and 1990; and the populations of major species of bottom-dwelling fish off Antarctica were seriously reduced barely a decade after large-scale harvesting began.[16] Third, as consumption/resource ratios rise simultaneously for a variety of resources, it can be harder to find relatively abundant resources to substitute for scarce ones.

The ingenuity requirement to compensate for scarcities of renewables is generally greater than that for nonrenewables.[17] Most renewables are embedded in highly complex, dynamic systems of resources. The overextraction of one resource in such a system can produce ramifying scarcities in the surrounding ecological system. As a result, the economic disruption caused by renewable resource scarcity is arguably often greater than that caused by nonrenewable scarcity: an economy not only has to find substitutes for goods and services provided by the scarce resource itself, it also often has to find substitutes for the goods and services that are causally dependent upon the resource.

Forests, for example, not only provide wood for fuel, construction, and paper. They also reduce the variance in the hydrological cycle by slowing the runoff of rainwater and by absorbing and releasing some of it through transpiration; they stabilize soils and reduce erosion; they absorb and fix atmospheric carbon dioxide that otherwise might contribute to global warming; and they provide a habitat for diverse organisms. In turn, each of these renewable services helps sustain other goods and services in the ecological system. Thus the loss of forests can generate much more than just a scarcity of wood: it can also generate scarcities of soils, of rainfall, of sustained and manageable river flow for hydropower and transportation, and of reservoir and irrigation capacity (since these systems become plugged with silt). If forest loss is widespread enough, it can diminish the biodiversity we need for our medicines and industries, and it might boost climate change. Some of these problems will induce yet other shortages: for instance, the silt that washes into the sea can smother coral reefs and thereby damage local fisheries.[18]

The fact that renewable resources are embedded within larger dynamic systems has another consequence: multiple scarcities can interact within the system to produce synergistic outcomes. An agricultural region may, for example, be simultaneously stressed by degraded soil and by changes in precipitation due to regional deforestation or climate change. The total impact of these interacting scarcities can be much greater than the sum of their separate impacts (Chen and Fiering 1989). Also, ecological systems often exhibit sharp and unanticipated threshold effects. They may respond slowly and incrementally to human intervention for a long period of time, and then suddenly change their character.[19]

The above characteristics of rising resource scarcity have implications for societies' capacity to adapt. As scarcities become more acute, societies will face an increasingly complex, unpredictable, and urgent decisionmaking environment that will boost the constant-satisfaction requirement for social and technical ingenuity. Scientists and engineers will need to respond to complicated and fast-paced substitution and conservation needs. Politicians, bureaucrats, corporate managers, and community leaders will have to adjust existing institutions and design, build, and operate new ones that allow technical ingenuity to flourish and that promote nontechnological adaptation to scarcity. People at all levels of society will have to minimize activities that deplete resources, to negotiate bargains among competing groups to diffuse scarcity's costs, and to encourage—perhaps through market mechanisms—the development of new technologies.

In his work on breakdowns in human-managed systems, the sociologist Charles Perrow introduces two concepts that are valuable here. He uses "complex interaction" to describe the effect of multiple and often unanticipated causal linkages and feedbacks among subsystems within a larger system. "Tight coupling" describes systems with little slack or buffering capacity between events and processes. Perrow argues that systems with both of these characteristics are unforgiving; a shock propagates rapidly and unpredictably through its components (Perrow 1984: 62–100).

To maintain satisfaction as consumption/resource ratios increase, humans will need to run resource systems ever more efficiently. System optimization will often demand tightly coupled and highly interactive horizontal and vertical management.[20] This management will require great ingenuity.[21] But even if the requisite ingenuity is supplied, the systems will still be vulnerable to sudden shocks, because many scarcities are interconnected and unpredictable, as noted above, and because efficiency and productivity requirements will tend to compress the time between events, reduce opportunities for recovery, and increase interactions between system elements.[22]

Furthermore, even with very good systems management, the physical, biological, and social laws that govern the world may make it difficult to fully compensate for the effects of scarcity. If such laws increasingly constrain a society's response to rising scarcity, then ever greater amounts of ingenuity will be required to circumvent these constraints.[23] Eventually, such laws may make it impossible to maintain aggregate social satisfaction.

Optimists are not daunted by problems of systems management or natural and social law. Humans, they argue, will be able to supply the needed ingenuity. I now turn to this issue.

Some factors limiting the supply of ingenuity

Every generation feels it lives on the cusp of chaos. People invariably believe that change is too rapid and that the world is becoming too complex and unpredictable, yet in the end they often manage well. In fact, the past two centuries have brought major material and social progress for much of humanity. Why should the future be different from the past? I argue here that some societies may not be able to supply the unprecedented amounts of ingenuity they will need to solve their emerging scarcity problems.

Many optimists implicitly assume that the price elasticity of supply of human ingenuity is nearly infinite, which suggests that an increase in demand for ingenuity will produce an equal increase in quantity supplied with no increase in price.[24] Neoclassical economists have also traditionally assumed that ingenuity—or "technology," as they usually call it—is available exogenously: it is a free public good that individuals, firms, and organizations access as necessary (Fagerberg 1994: 1149). These economists do not explicitly address where the technology originally comes from.

Other analysts argue that ingenuity is generated endogenously. There are several distinct perspectives here. Induced innovation theorists, such as the agricultural economists Yujiro Hayami and Vernon Ruttan (1971, 1985), propose that changes in factor endowments, notably of land, labor, and energy, are reflected in market price signals. These signals in turn stimulate technological innovations that loosen constraints on agricultural growth. Ruttan and Hayami (1984) acknowledge the critical intervening role—between price and technological innovation—of social institutions like property rights, financial agencies, and markets. However, they argue that demand for new institutions is largely determined, once again, by changes in factor endowments.

Similarly, Ester Boserup (1965, 1990) argues that cropland scarcity induced by population growth increases the input of labor into agricultural production and stimulates land-saving changes in cropping practices. Higher frequency of cropping encourages the evolution of secure private property rights, while infrastructural economies of scale produced by a larger population lead to the growth of markets and labor specialization.[25] Julian Simon (1981) further contends that larger populations mean more heads to generate the ideas that help societies overcome resource scarcity.[26]

New economic growth theorists also endogenize the generation of technologies. However, rather than focusing on the stimulus provided by changing factor proportions and prices, or on the idea-generating potential of a larger population, they focus on the relationship between the pool of human capital in an economy or firm and the generation of technology. This emphasis is not incompatible with the propositions outlined above: the induced innovation theorists stress how population growth and external stimuli produce innovation, whereas the new economic growth theorists stress the intervening processes that crucially involve human capital.

Optimistic views about ingenuity supply have not escaped criticism. Feeny, for instance, focuses on the supply of social ingenuity in the form of new institutions. He notes that many theorists interpret the Coase theorem to mean that societies will alter their institutions when benefits exceed costs.[27] "Although the authors do not, in general, explicitly state that change will occur whenever the marginal social benefits exceed the marginal social costs (including transaction costs) the lack of attention to the supply side of institutional change leaves that impression." He then gives pointed examples of the "failure to adopt innovations with positive net social benefits," and he concludes that "the supply of institutional change is important; trends in the demand, although necessary, are not sufficient for understanding the path of change" (Feeny 1988: 164–168).

I discuss here four factors that can limit the supply of social and technical ingenuity: market failure, social friction, shortage of capital, and constraints on science. Market failure and constraints on science are independent of resource scarcity; social friction and availability of capital are, I argue, sometimes affected by scarcity. Each of these four factors can interfere with either idea-generation or idea-implementation; in either case, they will not only limit the total supply of ingenuity but also limit the rate at which it is supplied. These factors can therefore induce critical time lags between the need for ingenuity and its supply.

Market failure

The traditional neoclassical model implies that an economy will supply the needed ingenuity if prices accurately reflect the costs of resource use. But prices often do not fully reflect these costs. Not only is ingenuity thereby undersupplied, but low resource prices encourage overconsumption of the resource, which can raise the constant-satisfaction requirement for ingenuity.

Two types of market failure are important.[28] First, many resources, especially renewables like hydrological cycles and productive seas, cannot be physically controlled or divided into saleable units for the exclusive use of specific consumers. It is therefore hard to assign clear property rights, and they remain "open-access" resources that are vulnerable to overexploitation.[29] At best, their scarcity is indirectly reflected in the prices of marketable resources that are dependent on them. For example, damage to ocean ecosystems can cause fish prices to rise.

Second, even if property rights are clear, market prices may still not fully reflect the costs of resource use. Resource extraction or use can produce "negative externalities"—such as river siltation from upstream deforestation—that are not incorporated in a resource's price. In addition, economic actors often cannot participate in market transactions in which they have an interest, either because they lack the necessary wealth or because they are distant from the transaction process in time or space. Finally, resource systems are often so complex that our knowledge of their functions and resilience, and of the likelihood of negative interaction and threshold effects, is grossly inadequate. Without good knowledge, it is impossible for either private economic actors or society to price resources accurately.

Unfortunately, even if prices accurately reflect the costs of resource use, ingenuity may still be undersupplied, because it has some characteristics of a public good. Rising resource prices may increase the demand for ingenuity, but ingenuity will be undersupplied if people cannot capture the social benefits of the ingenuity they produce.[30]

These problems are not insurmountable. Societies can try to provide secure, enforceable, and transferable property rights for both resources and ingenuity (thus the importance of improving systems of intellectual property rights); they can develop economic mechanisms to internalize more of the costs of resource use and to represent the interests of a broader range of parties; they can remove structural impediments to efficient markets, such as subsidies; and they can increase their knowledge of the services and functions of resource systems. But these tasks are not easy. "Getting the prices right" demands copious social ingenuity. Thus, paradoxically, market failures that negatively affect the supply of ingenuity increase the need for ingenuity to alleviate the very same market failures.

Poor countries are at a particular disadvantage because they start with underdeveloped economic institutions. They therefore need more social ingenuity to reform existing institutions and establish new ones. Modern markets are complicated and fragile social arrangements. They are defined and structured by a dense system of institutions, laws, rights, and norms, including laws that govern contracts and credit and discourage price-rigging and the excessive concentration of capital; limits on corporate liability; regulatory regimes for natural monopolies and stock and bond markets; a stable banking system; a predictable and restrained fiscal policy; a strong judicial system to enforce property rights and contracts; and agreements among levels of government permitting the movement of labor, capital, and other productive resources. Taken together, most of these arrangements increase the expected value of private gains and decrease the expected value of private costs from investment.

The state plays the central role in establishing this system of institutions. It must also provide other supports to an efficient market, including a competent civil service, high rates of literacy, a well-functioning infrastructure of transportation, communication, and irrigation systems, and a relatively egalitarian distribution of wealth.[31] Moreover, the public-good character of ingenuity means that the state must often intervene in the economy to increase ingenuity's supply through research, development, and extension services. The requirement for ingenuity within the state *itself* is therefore high: establishing a vigorous market in a developing country "demands accurate intelligence, inventiveness, active agency and sophisticated responsiveness to a changing economic reality" (Evans 1992: 148; see also p. 141).

Social friction

Scarcity can generate "social friction" that impedes the supply of social ingenuity in the form of new and reformed institutions, such as markets. Mancur Olson's pioneering work helps us understand how.

Olson (1982) analyzes the abilities of different social coalitions—from unions to farm and manufacturing associations—to provide collective goods for their members despite the tendency of members to free-ride. For our purposes, he makes three critical points. First, he shows that small coalitions can generally organize themselves more quickly and pursue their interests with greater force than large groups.[32] They therefore have political power disproportionate to their size, and they can be more nimble, focused, and effective in their lobbying.

Second, Olson notes that this disproportionate power will be particularly acute in "unstable" societies, a category encompassing many developing countries, because large coalitions need time and social stability to establish themselves and grow. The governments of unstable countries are therefore "systematically influenced by the interests, pleas, and pressures" of small coalitions (1982: 165).

Third, small coalitions invariably pursue narrowly defined self-interest and are unlikely to act on behalf of the commonweal. They are almost exclusively "distributional coalitions," since they strive to redistribute the wealth in the system rather than to increase it. For all practical purposes, Olson writes, there is "no constraint on the social cost such an organization will find it expedient to impose on the society in the course of obtaining a larger share of the social output for itself" (1982: 44).

Increased scarcity often provokes vigorous action by groups to protect their interests. Building on Olson's arguments, we can assume that small coalitions generally defend their interests better than large ones, especially in developing countries; those that already have wealth, power, and status because of their position in the social order are particularly advantaged. Furthermore, as noted earlier, future resource scarcities are likely to create a more complex, unpredictable, and urgent decisionmaking environment in societies. This environment will accentuate the relative power of small coalitions, since they can more quickly identify their interests and focus their efforts.

Because small coalitions usually have narrow interests, their actions often impede the institution-building that reflects the broader interest of society. They hinder efforts to reform existing or establish new social institutions, laws, and behaviors if these efforts encroach on coalition interests, as they often will.[33] This "social friction" makes it harder to focus and coordinate human activities, talents, and resources in response to scarcity. As Olson says, narrow coalitions "interfere with an economy's capacity to adapt to change and to generate new innovations" (1982: 62). Thus the coalitions provoked to action by scarcities will sometimes block solutions to the very same scarcities.[34]

How might narrow coalitions have this effect? One mechanism is particularly important. Public institutions will be supplied at the socially optimum level only in specific circumstances: the private rate of return to the political entrepreneurs who can create these institutions must approach the social rate of return (Feeny 1988: 169–170; North and Thomas 1973: 69–70). The actions of narrow coalitions can raise the private costs and reduce the private benefits of such institution-building, which in turn increases the gap between private and social returns and results in a socially suboptimal supply of institutions. Ruttan and Hayami thus note (1984: 213) that "the supply of institutional innovation depends critically on the power structure or balance among vested interest groups in society" (see also Feeny 1988: 167).

In light of this discussion, it appears that two characteristics of a society will especially influence how much social friction is caused by scarcity and the extent to which this friction hinders the supply of ingenuity. First, a society will manifest greater social friction if its culture encourages selfish individual or group behavior; a "culture of selfishness" causes people to retreat more quickly into narrow coalitions as scarcity worsens. For example, Filipino culture encourages cooperation within groups rather than among groups; the resulting isolation of groups from each other—the oft-remarked clannishness of the society—undermines the concept of national welfare (Kessler 1989: 18). As a consequence, "severe want and poverty do not produce cooperation but rather seem to encourage indifference and greed" (Guthrie 1968: 79).

The opposite of a culture of selfishness is a culture of good will, civic-mindedness, and trust. Social theorists acknowledge the importance of these virtues to economic wellbeing.[35] A culture with strong norms of civic-mindedness can impede the rise of narrow coalitions as scarcity worsens. In fact, scarcity can sometimes lead to greater unity and commitment to the common good, rather than to fragmentation. Thus Geertz observed that the burden of poverty caused by scarcity of cropland in Java was shared among community members (1963: 96–100).

Second, if narrow coalitions have already penetrated the state, social friction will have a particularly strong effect on society's capacity to reform and build institutions. Such a state will tend to grant monopoly rents to powerful coalitions when they mobilize to defend their interests (North and Thomas 1973: 98–99). And because acute scarcity makes it easier to establish monopoly control over resources, it increases opportunities for rent-seeking behavior. Once entrenched, these rent-seekers are potent obstacles to institutional reform. The degree of penetration is affected by the broader institutional character of the society. Indian democracy, for example, has encouraged the mobilization of narrow coalitions, yet India does not have strong political parties that can mediate between these coalitions and the state. The result is a state deeply penetrated by narrow coalitions. This "interest group activism in a weak-party democracy has contributed to deceleration of public investment and low economic growth rates" (Kohli 1987: 242).

Much like market failure, social friction that reduces the supply of ingenuity also pushes up the requirement for ingenuity. Increased social friction boosts the complexity of a political and economic situation that may already be highly complex because of scarcity. Governments, policymakers, and community leaders need more ingenuity to generate solutions to gridlock brought about by these coalitions and to motivate, coopt, coerce, and circumvent obstructionist groups.

The counterargument here is that conflicts caused by scarcity, rather than interfering with the supply of ingenuity, often generate greater creativity and opportunities for innovation. In particular, violent revolution by exploited groups can dissolve rigid social relations that obstruct beneficial institutional and economic change. I agree that sclerotic and exploitative social structures can reduce the supply of ingenuity and that, sometimes, severe conflict is needed to change them. But if the state is penetrated by rent-seekers and status-quo interests, successful and sustainable institutional reform through conflict usually requires that one of the groups challenging the state win the conflict; once in control of the state, the victorious group can reestablish order and build new institutions. If challenger groups cannot win and severe conflict persists within the society, new institutions will not take root. In addition, such conflict usually destroys knowledge and physical assets, producing long-term economic and political debilitation—and a reduced supply of ingenuity—after the conflict ends.

Capital availability

The amount of ingenuity supplied in response to scarcity will generally be lower in societies with less financial and human capital. Capital is needed for vigorous research into opportunities for mitigating and adapting to scarcity. Access to credit helps private entrepreneurs exploit these opportunities and diffuse useful knowledge through the broader economy. Political entrepreneurs need financial capital to provide selective incentives and side payments to coalitions that obstruct institutional change. And the state needs capital to provide public goods like infrastructure and resource monitoring.

Many societies facing serious resource scarcities are poor; moreover, the often predatory behavior of their elites further reduces general capital availability. Technological research is therefore not well supported, causing heavy reliance on externally developed and often inappropriate technologies (Grossman and Helpman 1991). Capital shortages lead to deteriorating or inadequate transportation and communications systems and make it difficult for states to implement new policies in response to scarcity or to enforce laws on resource use.

Shortages of human capital frequently cripple the supply of ingenuity. In 1980, sub-Saharan Africa had about 45 scientists and engineers in research and development for every million people, while the figure in developed countries was 2,900 (Repetto 1987: 37). Since then, the situation in Africa has worsened. The United Nations reports that by 1987 nearly a third of Africa's highly skilled labor had left for Europe and that the continent as a whole lost 60,000 middle and high-level managers between 1985 and 1990 (United Nations Development Programme 1992: 57). In India, 30 percent of graduates of the Indian Institute of Technology in Bombay have emigrated since the early 1970s, as have 45 percent of graduates of the All-India Institute of Medical Sciences (*Nature* 1993: 618).

Increasing resource scarcity can affect capital availability by decreasing savings and diverting capital to serve short-term needs. Severe scarcity often shortens society's time horizons and thereby shifts funds from savings to consumption; it also shifts investment from long-term adaptation to immediate tasks of scarcity management and mitigation. In the face of agricultural shortfalls caused by soil erosion, for instance, societies tend to invest first in fertilizer production and imports and only later in research on erosion-resistant crops. This diversion of capital from long-term projects particularly debilitates the creative interdisciplinary research that is essential for social adaptation to scarcity; such research is invariably funded last.

Constraints on science

Modern science—a key to the supply of technical ingenuity—faces four constraints that will affect society's ability to adapt to resource scarcity. First are human cognitive limits.[36] Humans do not have infinite ability to understand and manage the complex, multivariate processes of ecological and social systems. The relationships in some of these systems are "simply too numerous and complex to be grasped, much less controlled, by the human intellect" (Manning and Rejeski 1993; see also Wilson 1993). These cognitive limits are likely to be more serious when human capital is in short supply, because individual experts and decisionmakers face a greater load of tasks.

A second constraint on science is the escalating cost of research. In general, research becomes more expensive as it advances (de Solla Price 1986: 82). Many of the scarcities confronting developing countries demand highly advanced science like molecular biology that poor societies cannot afford, especially when faced with capital shortages. A third constraint arises from the cumulative nature of scientific knowledge: each new discovery must build on a host of earlier ones. The pace of discovery is marked by jumps and lags as scientists make breakthroughs or lose time pursuing fruitless leads. This pace cannot be easily forced, especially in basic science where the work's ultimate practical use is not clear. Even if a discovery has a clear use, its diffusion in usable form throughout society often takes decades.[37]

A final constraint is science's vulnerability to the social turmoil that scarcity can cause. Science is a fragile social process that requires not only a great variety and abundance of resource inputs, but also a nonhierarchical institutional structure, a dense network of connections between like-minded innovators, and a popular culture that respects and promotes science (Watt and Craig 1986: 199). Recent developments in Russia show science's sensitivity to social context: the society's turmoil has crippled its vast research establishment and has caused a decline in respect for analytical thought and a sharp rise in occult and antiscience movements (Wright 1991; Kapitza 1991).

Conclusions

I have argued that understanding the determinants of social adaptation to resource scarcity requires examination of the role of ingenuity, and I have suggested several factors that can limit the supply of ingenuity. Other analysts might argue that scarcity will tend to stimulate a sufficient flow of ingenuity to offset these factors. Or they might contend that new developments in national and international economies, including increased trade and investment and the vastly increased flow of ideas through expanded communications networks, will provide enough ingenuity when and where it is needed. Although not entirely convinced by such claims, I have mainly sought to reframe the debate on adaptation to scarcity and to raise some issues deserving further investigation.

My argument here allows us to synthesize the three seemingly irreconcilable positions mentioned at the beginning of this article. Neo-Malthusians emphasize physical causes of scarcity and poverty: population size and growth, the resource-consumption rate per capita, and the quantities of natural resources available to a society. Neoclassical economists and distributionists, on the other hand, emphasize social causes like ineffective markets, bad economic and social policies, and skewed resource distribution among classes and groups. In contrast, I integrate both types of variables. Social improvements such as better markets and resource distribution, which are products of ingenuity, often alleviate scarcity. But a society's capacity to make these improvements will be partly determined by scarcity itself, which is powerfully influenced by the society's physical context. More generally, while the behavior of social systems is not fully determined by their physical context, neither is it independent of this context.

My argument also helps us rethink the issue of limits to growth, and in the process it helps us understand why, in many cases, resource scarcity does not impede the growth of prosperity, while in other cases it contributes to long-term economic decline. The limits a society faces are a result of the interaction of the society's physical context with the ingenuity the society can bring to bear on that context. If humans could supply infinite ingenuity, then the maximum sustainable limit for population and consumption would be determined by physical law. Since infinite ingenuity is never available, the limits societies face are more restrictive than this theoretical maximum. And since the supply of ingenuity depends on many social and economic factors and can therefore vary widely, we cannot determine a society's limits solely by examining its physical context. Rather than speaking of limits, therefore, it is better to say that some societies are locked into a race between a rising requirement for ingenuity and their capacity to supply it.

If a country loses the race, social dissatisfaction will rise, with increasing stress on marginal groups, including those in ecologically fragile rural areas and urban squatter settlements. A persistent and serious ingenuity gap will cause major social changes like declining food production, reduced economic production, and large population movements. These changes undermine regime legitimacy and coercive power and increase the likelihood of widespread and chronic civil violence (Homer-Dixon 1991, 1994). Serious strife will, of course, further debilitate what remaining capacity the society has to supply ingenuity in response to the original scarcity, especially by causing capital to flee. Countries with a critical ingenuity gap therefore risk entering a downward and self-reinforcing spiral of crisis and decay.

Although many analysts might reach a different conclusion, I believe we will see an increasing bifurcation of the world into societies that can maintain an adequate supply of ingenuity and those that cannot. Future resource crises and the social hardships that accompany them will be regional rather than global. We may see, for example, falling grain prices and regional food surpluses in Western countries occurring simultaneously with scarcity-induced civil strife in parts of Africa and Asia.

My argument also has implications for the debate over intergenerational equity. Neoclassical economists often note that the costs of conserving natural resources are usually borne in the present while the benefits arrive only in the future. Given that society has a positive discount rate, they claim, it makes more sense for poor countries to invest in economic growth and thereby bequeath greater capital to future generations. Their descendants can use this capital to address the resource scarcities they face at that time. I have argued that extra capital will indeed aid the supply of ingenuity. But there are also disadvantages to waiting: future generations may have to face scarcities much more complex and urgent than today's, which could raise the need for ingenuity; furthermore, future societies may experience greater social friction due to scarcity, which could impede ingenuity supply. It seems quite possible that the additional capital will not, by itself, compensate for this ingenuity deficit.

My analysis puts a premium on prevention of scarcity, not on ex post facto adaptation to it. The optimism of those who have great faith in the potential of human ingenuity when spurred by necessity is, I believe, imprudent. We are taking a huge gamble if we follow the path they suggest, which is to wait until scarcities are critical and watch human ingenuity burst forth in response. Should it turn out that this strategy was wrong, we will not be able to return to a world resembling the one we have today. We will have burned our bridges: the soils, waters, and forests will be irreversibly damaged, and our poorest societies will be so riven with discord that even heroic efforts at social renovation will fail.

Notes

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1 Neoclassical economics is a body of theory grounded in nineteenth-century marginal economics that emphasizes the relationship between factor prices and scarcity, the rational maximizing behavior of individuals in markets, the idea of a perfectly competitive economy in equilibrium, and the market's natural tendency toward full employment.

2 Clear statements of the neoclassical position are Barnett and Morse (1963); and Smith (1979), especially chapter 2 by Stiglitz. There are many similarly optimistic, although not all strictly neoclassical, accounts of human capacity to adapt to population growth and land scarcity. See in particular Boserup (1965); Hayami and Ruttan (1971, 1985); and Tiffen, Mortimore, and Gichuki (1994).

3 Nonrivalry is distinct from nonexcludability. A good is nonexcludable if access to it cannot be prevented. Romer notes that ideas may be partially excludable, through such devices as intellectual property rights or temporary monopolistic control of ideas through market power. A pure public good—such as national defense—is both nonrival and nonexcludable. For further details, see Cornes and Sandler (1986).

4 Although various authors, in particular Julian Simon (1981), have discussed the importance of ingenuity in human responses to scarcity, it has never been defined or applied with the precision attempted in this article.

5 What counts as a practical problem needing to be solved—and what in turn counts as ingenuity—is partly determined by cultural context. But there are limits to this cultural plasticity, because certain requirements for ingenuity are common to all cultures: all humans, for instance, have basic needs for food, water, and shelter.

6 Using a chemistry set metaphor, Romer (1993b: 68) represents a given mixture of chemicals—his analogue to an "idea"—by a string of 0s and 1s. A position in the string is assigned to each substance in the chemistry set. The position shows 1 if the substance is included in the mixture and 0 if it is not.

7 For similar arguments on how social institutions shape a society's capacity for technological development, see Gerschenkron (1962); Abramovitz (1986); and Johnson (1992). On the general relationship between institutions and economic growth, see North (1990).

8 Surprisingly, people are often perplexed by the claim that something can be both an input to and an output of the economic system. However, a moment's reflection shows this is the case for many goods. Physical and human capital, for example, are both inputs and outputs: an economy needs factories to produce the components for further factories, and engineers to train engineers.

9 "The word technology invokes images of manufacturing, but most economic activity takes place outside of factories. Ideas include the innumerable insights about packaging, marketing, distribution, inventory control, payments systems, information systems, transactions processing, quality control, and worker motivation that are all used in the creation of economic value in a modern economy" (Romer 1993a: 544).

10 I assume that there is a rough consensus within society on what constitutes social welfare, although the consensus may change across societies and over time. Economists acknowledge that it is both hard to specify exactly what counts as individual welfare and hard to aggregate individual welfares to arrive at a measure for the whole society. See Sen (1984: 307–324).

11 Society's actual *demand* for ingenuity, in contrast, depends on its price. Often, ingenuity's price is the wage to the human capital that generates it; examples include the salary paid to an engineer and the remuneration to a consulting firm. Sometimes ingenuity is bought directly, as when a fee is paid for a license to manufacture a patented product.

12 The classic treatment of the second stage is Rogers (1983).

13 This general claim, while reasonable for heuristic purposes, needs several qualifications. First, some renewable resources—like agricultural soils, climate, and the stratospheric ozone layer—mainly provide economic services, not goods. In the case of excludable renewables that provide services, like agricultural land, the resource is not so much "consumed" as "used" (although there is some consumption of the nutrient stock in the soil); the ratio, in this case, is better stated as total cropland used to total potential cropland available. In the case of nonexcludable renewables that provide services, like the ozone layer, the sink or absorptive capacity of the resource is often degraded by human activity, and the appropriate ratio might be the total emissions (of CFCs, for example) to total absorptive capacity.

Second, it is notoriously hard to define, in any objective way, the total quantity of a resource available for consumption or use (the denominator of the ratio). Renewable resources are characterized by both a stock and a flow; resource availability, therefore, depends on whether one regards the underlying stock as available for consumption. Also, the stated reserves of a resource tend to be affected by the resource's price, since the higher the price the greater the incentive to obtain the resource. And, technical ingenuity changes both the availability of resources (through more efficient extraction technologies, for instance) and the definition of what is, and what is not, a useful resource.

Third, while per capita resource consumption is rising rapidly in most developing countries, the 1970s saw a reversal of this trend in industrialized countries. Per capita consumption (and in some cases total consumption) of basic industrial materials—such as steel, cement, aluminum, and paper—began to decline, although the drop remains small compared to the growth that occurred in this century. See Larson, Ross, and Williams (1986).

14 Many analysts use similar concepts. Daly and Cobb (1989: 143–147), for example, discuss the "optimal scale" of the global economy in relation to the planet's resource base. See also Pearce and Turner (1990: 290–295); and Raskin, Hansen, and Margolis (1994: 12–13).

15 On the cod fishery, see Harris (1990); on Middle East water shortages, see House of Representatives (1990); and on Chinese cropland loss, see Smil (1993).

16 On West African forests, see World Resources Institute (1992: 119); and on Antarctic fisheries, see World Resources Institute (1990: 193).

17 Economists generally contend that scarcities of renewables and nonrenewables pose similar economic problems and consequently stimulate similar conservation, substitution, and innovation effects. To the extent that economists acknowledge a difference, it is in the cause of scarcity: renewables are more often "open access," and therefore tend to be depleted or degraded more quickly and with less effect on market prices.

18 In contrast, the loss of a body of a nonrenewable resource like iron ore has no ramifications within the ecological system. The ore's increased scarcity will not affect surrounding renewable and nonrenewable resources, because a body of ore is ecologically inactive. Of course, the extraction process—which may involve heavy equipment, explosives, and chemicals—can damage renewables like local rivers and forests.

19 A common example is the collapse of the Peruvian anchovy fishery in the 1970s. On nonlinearities in ecological systems, see Ludwig, Hilborn, and Walters (1993).

20 Horizontal management operates at a single level of social organization such as the village or nation-state; vertical management cuts across these levels, integrating, for example, the village, national, and biospheric levels.

21 "Such a society would be characterized by great efficiency in resource use, very diverse energy and materials sources and pathways through the system, a very large number of types of system components (i.e. occupations), and a rich variety of internal control mechanisms" (Watt and Craig 1986: 197).

22 Attempts to optimize system performance produce complexity, as do attempts to deal with the negative consequences of previous increases in complexity. See Arthur (1993).

23 These constraints include time lags governing the mitigation of scarcity, such as the time needed for a new forest to grow, for a new technology to be disseminated, or for cultural change to occur. Physical law influences the elasticity of substitution of ingenuity for a given resource; if the elasticity is low, then a large amount of ingenuity is needed to compensate for a small increase in scarcity. The second law of thermodynamics has received particular attention. As Dyke (1988: 365) notes, the law "defines a space of possibilities for us, and does so rather tightly."

24 Jacob Schmookler (1966: 204) suggests, for example, that "the S-shaped long-run growth curve for individual industries, in which output tends to grow at a declining percentage rate, usually reflects demand, not supply, conditions." The growth curve reflects the declining marginal utility of production, rather than its increasing marginal cost.

25 Such arguments have a long history: see, for instance, Dupréel (1928).

26 A recent close study of the semiarid Machakos District in Kenya (Tiffen, Mortimore, and Gichuki 1994) lends support to these various claims.

27 The Coase theorem is "based upon the argument that externalities do not give rise to a misallocation of resources provided there are no transaction costs, and given property rights that are well-defined and enforceable" (Pearce 1986: 66).

28 For a technical discussion, see Dasgupta and Mäler (1994: 22–30).

29 Some renewables, such as forests, have physical characteristics that permit the assignment of clear property rights; nonethe-

less, they are often open-access resources because of historical norms and laws governing their exploitation.

30 Romer (1993b: 89) thus contends that "we must recognize that ideas are economic goods that are unlike conventional private goods, and that markets are inherently less successful at producing and transmitting them than they are with private goods."

31 The role of the state in establishing the conditions for markets has long been noted; of particular importance is Polanyi (1957: 139–140).

32 Bargaining costs are lower within small groups; group homogeneity tends to be higher, thus reducing disputes over the nature of the collective good sought; the need for selective incentives is lower because collective benefits are shared by fewer members; and small groups can provide "social" selective incentives, such as ostracism and respect.

33 Many analysts emphasize how narrow coalitions impede sustainable economic development and adaptation to resource scarcity. See Reed (1992); Ostrom, Schroeder, and Wynne (1993); Ludwig, Hilborn, and Walters (1993); and Ruttan (1989: 1384–1385).

34 Scarcity also causes a *diversion* of ingenuity to serve the interests of narrow coalitions; thus, even if society's total supply of ingenuity does not decrease, its supply for public institution-building can decline.

35 See, for example, Hirschman (1992: 153–157); Putnam (1993); and Sabel (1992).

36 For a review, see Winner (1975).

37 For example, research shows a historically consistent interval of 20 to 40 years for substitutions involving metals. See Gordon et al. (1987: 65).

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