Hayek Revisited

Planning, Diversity, and the Vox Populi

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By the end of the 1980s, many writers, both in scholarly literature and in the popular press, had come to the conclusion that the twentieth century's great experiment with socialist planning had produced economic results that were by and large disappointing, if not decisively so. Even Mikhail Gorbachev, who remains an ardent believer in socialism's potential to produce wealth, wrote candidly in *Perestroika* of "the disastrous state of the Soviet economy"(1987, 10). Within fours years of his book's publication, Gorbachev had failed in his attempts at economic reform, and the Soviet Union itself ceased to exist.[1]

Scholars in various disciplines have reflected on the demise of the Soviet Union and other planned economies, but other analysts foresaw the failure of central planning long before this point. Among these prescient analysts, few have been as influential as F. A. Hayek. His 1944 book *The Road to Serfdom* is perhaps his profoundest critique of socialism. John Maynard Keynes famously declared that he was "not only in agreement with it, but in deeply moved agreement."[2] Hayek's more theoretical essays on the nature of economic information and the use of knowledge in society are less accessible, but perhaps of greater importance among economists. The central theme of Hayek's "knowledge" arguments is that planning authorities cannot effectively manage all of the knowledge necessary for successful economic planning be-

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1. For an excellent discussion of Gorbachev's reform movement, see Boettke 1993.

2. Quoted on the cover of the 1975 Phoenix Books edition of *The Road to Serfdom*.

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cause such knowledge is by its very nature fragmented, dispersed, ever changing, and ultimately subjective.

Hayek offered more than a critique of planning, of course. He wrote eloquently and at length on the workings of the market system, which, he argued, gathers and communicates economic information and knowledge marvelously well, if still not perfectly.[3] Although separate individuals within the market system obviously possess only bits and pieces of information, the totality of market knowledge, as embodied implicitly in relative prices, is much more complete than the knowledge available in explicit form to a central planning authority.

In this article, I examine certain elements of Hayek's writings on socialism and the use of knowledge and relate this work to a new research program that is yielding interesting implications for the debate over planning versus markets, particularly for the Hayekian critique. The upshot of this new research is that the collective wisdom of a large number of persons, hereafter designated by the term *vox populi,* is often superior to the judgments of the few, even an extremely knowledgeable few. This scholarship establishes new theoretical support in highly formal analysis for Hayek's common-sense (my description, not his) argument that the collective wisdom of the market is superior to the judgments of experts within the planning system.[4]

Little has been written on the implications of the new research for Hayek's critique of collectivist central planning—not a surprising state of affairs, given that the new research is still at a fairly early stage of development and that much of it is coming from outside the science of economics.[5] Perhaps another reason for this pretermission has to do with the extremely formal and technical nature of this new research. Those not trained in *both* higher mathematics and the methods of computer simulation will find the primary literature difficult at best, if not altogether incomprehensible. The discussion here provides an intuitive interpretation of the new research and explores its implications for the Hayekian critique of socialism.

The first order of business is to examine Hayek's argument more closely. A comprehensive examination of his writings would take us far beyond the scope of the current article, but a focused review can clarify certain key elements in his critique of central planning and place the rest of the present discussion in proper context, both within history and in relation to Hayek.

Hayek and the Socialist Calculation Debate

Although *The Road to Serfdom* was Hayek's most popular book to date, it was not the first thing he had written on socialism. In 1935, he edited *Collectivist Economic*

3. Hayek himself described the market as a "marvel" in order to "shock the reader out of the complacency with which we often take the working of this mechanism for granted" (1948, 87).

4. One should not infer that the researchers themselves necessarily agree with this position. The thesis that the vox populi implies the superiority of laissez-faire economic policy is mine, not necessarily theirs.

5. I am aware of no one writing in the scholarly literature of refereed journals who has made the connection. Surowiecki does make brief mention of Hayek but devotes only one sentence to him (2004, 71).

Planning: Critical Studies on the Possibility of Socialism, which provided English translations of several essays that had appeared previously in German. In one of these essays, the Austrian economist Ludwig von Mises argued that rational economic planning would be impossible without the pricing mechanism of the free market (Mises [1920] 1935).[6] Without market prices, Mises reasoned, there would be no way to determine relative scarcity accurately and therefore no way to allocate resources efficiently.

Mises had first made the argument as early as 1920, yet socialists in the 1930s remained convinced of the *theoretical* possibility of rational economic calculation in a planned economy (see, for example, Dickenson 1933; Lerner 1937; and Lange 1938). They argued that any economy, small or large, simple or complex, could be represented formally by a Walrasian system of equilibrium equations, which theoretically could be solved by the market or by the planning authority. Accounting prices could be provided on a provisional basis by the planning authority, rather than the market, and managers could then attempt to maximize profits on the basis of those prices. The authority could periodically adjust prices as needed, thus approaching the "correct" set of prices by a process of trial and error. Prices were necessary, as Mises contended, but *market-determined* prices were not.

In this perspective, socialism's success becomes a practical, not a theoretical, matter: Could a nonmarket approach actually work as well in practice as a market-oriented system? Oscar Lange, perhaps the most important of the early socialist economists, held that socialism would in fact outperform the market. The planning approach, he maintained, would achieve equilibrium more directly than the market because the planners would possess superior knowledge: "[T]he Central Planning Board has a *much wider knowledge* of what is going on in the whole economic system than any private entrepreneur can ever have, and, consequently, may be able to reach the right equilibrium prices by a much shorter series of successive trials than a competitive market actually does" (1938, 89, emphasis added).

Hayek, more so than Mises, directly considered the issues Lange and other socialist economists of the 1930s raised. Hayek's arguments fall generally into three categories: complexity, subjectivity of knowledge, and dispersion of knowledge.

The first set of responses dealt with the practical feasibility of managing the economy within the framework of Walrasian equilibrium equation systems. Hayek rejected this approach, "the mathematical solution," as impracticable and unfeasible (1935, 207–14). He emphasized the enormous difficulties of correctly specifying the many thousands of equations composing the system; of collecting the enormous amounts of data needed to provide empirical, quantitative directives; and of the need constantly to solve and resolve the equations as supply and demand conditions

6. Mises's article "Economic Calculation in the Socialist Commonwealth," reprinted in Hayek 1935, was originally published in 1920 as "Die Wirtschaftsrechnung im Sozialistischen Gemeinwesen" in *Archiv fur Sozialwissenschaften* 47.

change. The complications attending change itself are significant: even if the computations could be performed and a set of end-point solutions calculated, they would represent *obsolete* solutions by the time they were known and could be acted upon.

Hayek made these arguments before the advent of supercomputers. Lange would claim much later that the development of high-speed computers overcomes most of the complexity problems (Feinstein 1967, 158), but Don Lavoie (1990) has noted a certain irony in the literature of "artificial intelligence" research: rather than offering computer simulation models as superior substitutes for the market, researchers are attempting to develop computer models that mimic the functional characteristics of markets. If Lavoie is correct in his assessment, then it would seem that Lange's argument is being stood on his head.

Hayek's "subjectivity of knowledge" arguments speak to issues beyond practical computational difficulties and arise out of his understanding of the nature and use of knowledge. These arguments draw a crucial distinction between objective, "explicit" knowledge and more inarticulable, ultimately subjective knowledge. A sense of the difference is conveyed in contrasting "information" with "understanding." The use of the term *information* in current economic theory is very close to what Hayek meant by "explicit" knowledge—little pieces of data, bits (or bytes) of factual content that can be gathered and transmitted from person to person in objective, even numerical terms. Possessing the "optimal amount" of such knowledge means equating the costs and benefits of information search at the margin. Contrast this objective information with the sort of understanding that invests entrepreneurial decision making: the special insights into consumers' wants, local conditions, and special circumstances; the recognition of unexploited opportunities; a "feel" for technology and its potential applications. These are examples of subjective knowledge, which Hayek also described as "tacit" (1935, 522). Such knowledge is not only highly localized, but can sometimes be as subjective as a hunch or an intuition.

It follows from the nature of tacit entrepreneurial knowledge that production costs are not objectively given, but subjectively estimated on the basis of expectations, perceptions, and consequences foreseen. As such, they become *known facts* only in hindsight, if at all. But planning, by definition, is future oriented. It is therefore illusory to believe that the information available to the planning authorities is actually anything other than *yesterday's* facts. Whether Hayek himself made enough of this point is debatable (Buchanan 1969, 22). Eric Streissler argues that Hayek failed to press adequately the related point that tacit knowledge is agent specific (1994, 66). Different entrepreneurs know different means and methods of production, which brings ambiguity to the planners' collective valuation of input factors and ultimately plays havoc with the whole planning system.

Leland Yeager maintains that entrepreneurial knowledge is a resource that would "go to waste [in a socialist system], even if it emerged in the first place" (qtd. in Caldwell 1997, 1866) because entrepreneurial knowledge is not translatable into numerical data or other forms of explicit information. Moreover, such knowledge

might never emerge in a socialistic environment "in the first place" because socialism might not provide sufficient incentives to be creative, a major requirement for long-term success in the competitive world of market rivalry. Hayek himself raised the issue of incentives in both *Collectivist Economic Planning* (1935, 206, 233–36) and *The Road to Serfdom* (1944, 122–33). The problem, he argued, was not merely that socialism tends to foster laziness or a lack of willingness to do one's best, although he believed that it probably does have this deleterious effect upon many (1944, 125). Rather, the more important problem involves *signaling;* it has to do with a lack of information, not personal character.[7] Hayek believed that socialist means of allocating labor fail to give workers an "intelligible yardstick by which to measure the social importance of different occupations." Thus, "it would be impossible for anyone intelligently to choose between various alternatives if the advantages they offered him stood in no relation to their usefulness to society" (1944, 125). Here Hayek refers to the economic incentives involved in the allocation of labor among different employments. And what of that special kind of human resource, entrepreneurship?

Hayek also clearly recognized that the institutions of free-market capitalism encourage entrepreneurial creativity, alertness, and discovery. In the essay "Competition as a Discovery Procedure," he wrote that free-market institutions "provide . . . a sort of discovery procedure . . . which provides the incentive for constant discovery of new facts which improve adaptation to the ever changing circumstances of the world in which we live" (1978, 236). Hayek had much earlier recognized another potential incentive problem for entrepreneurs in a socialist system: they might be overly safe and protective in their investment strategies. "Risky and even purely speculative endeavors will be no less important here as under capitalism. . . . [But] how long is a formerly successful entrepreneur to be suffered to go on making losses? . . . Under capitalism, too, loss of capital may mean loss of status as capitalist. But against this deterrent is always the attraction of the possible gain. Under socialism this cannot exist" (1935, 234–35).

Those who have chided Hayek for ignoring incentive issues (for example, (Markowski and Ostroy 1993) may not be giving him his full due. In any event, however, modern theorists were certainly quicker to embrace and today are generally more familiar with his "dispersion of knowledge" arguments than they are with either the complexity or subjectivity arguments (Caldwell 1997, 1866). As noted earlier, the "dispersion of knowledge" arguments grew out of Hayek's response to those who contended that the planning authority would have at its disposal superior knowledge and information, or, in Lange's words, previously quoted, "a much wider knowledge of what is going on in the whole economic system than *any private entrepreneur* can ever have" (emphasis added). Hayek believed that the socialists failed to grasp the real issue: "the main merit of real competition is that through it use is made of knowledge

7. Hayek may not have recognized fully the "agency" problem that arises from asymmetric information (Caldwell 1997, 1876–877).

divided among many persons which, if it were to be used in a centrally directed economy, would have all to enter the single plan. To assume that all this knowledge would be automatically in the possession of the planning authority seems to me to miss the main point" (1935, 134).

If the planning board has wider knowledge than any *single* entrepreneur can have, the issue for Hayek is whether the planning board can have wider knowledge than entrepreneurs in the market have *collectively*. The question becomes how best to approach the use of knowledge, when that knowledge is fragmented and dispersed among many different entrepreneurs throughout society. The planning system requires that all relevant economic information be gathered in "raw" (that is, specific and explicit) form and centralized in the hands of the planners—in Hayek's view, an impracticable undertaking. But the decentralized market system, he maintained, is reasonably good at gathering and communicating such information implicitly in the form of prices: "The whole acts as one market, not because any of its members survey the whole field, but because their limited individual fields of vision sufficiently overlap so that through many intermediaries the relevant information is communicated to all. The mere fact that there is one price for any commodity . . . brings about the solution which (it is just conceptually possible) might have been arrived at by one single mind possessing all the information which is in fact dispersed among all the people involved in the process" (1948, 86). Hayek's point is that something akin to "one single mind possessing all the information" does exist—not in the single mind of the planning authority, but in the form of the market price. Prices are "condensed" information—less explicit, but not less comprehensive than the planners' centralized "raw" economic data. The market price thus "brings about the solution" that manifests a *collective wisdom* of sorts in the administration of economic resources. By *collective wisdom,* I understand a decision or judgment that embodies the diverse perspectives of the many who participate in the market, as distinct from the *collectivist* perspective of those who constitute Lange's central planning authority. Hayek's critique rejects the collectiv*ist* judgment of planning authorities in favor of the collective wisdom of the market.

My review of Hayek's critique of socialism has considered three general lines of argumentation pertaining to complexity, subjectivity, and dispersion of knowledge.[8] It is safe to say that modern mainstream economists in general consider the "dispersion" arguments to be Hayek's most significant contribution to the debate over planning versus the market (Caldwell 1997). For my present purposes, however, these arguments are indeed principal because the new research into collective problem solving deals with what is, most essentially, a dispersion-of-knowledge problem.

8. The three are conceptually distinct, but not unrelated. Dispersed knowledge may be fairly objective (albeit localized), or it may be highly subjective (perceptions, expectations, and other entrepreneurial insights). The complexity argument is about mathematical, computational difficulties that are exacerbated in practice by both the dispersion and the subjectivity of knowledge.

These models place problem-solving agents in an information environment in which knowledge is fragmented, scattered, and not given in its entirety to any one entity. The agents' success depends on their ability to achieve a collective knowledge—the vox populi—of the problem domain, given the dispersion of knowledge among the many members of the group. The researchers themselves do not present their work as a validation of Hayek's views; in fact, they do not even mention Hayek. It is my argument, not necessarily theirs, that this new research yields supporting evidence for the Hayekian critique of planning.

Before we move on to the new research on diversity and group decision making, we should digress briefly to distinguish the vox populi from a closely related phenomenon, the "invisible hand." Both lie at the heart of the argument that markets are more efficient than central planning, and both are necessary to establish that conclusion. The two have traditionally been treated implicitly as one, but it is helpful to separate them so that we can narrow the focus of the discussion and eventually concentrate on the vox populi and its relevance to Hayekian thinking, its surprising degree of validity, and the role of diversity in making it so.

A Digression: The Invisible Hand and the Vox Populi

Socialist planning and market processes present very different forms of economic organization. The socialist form is guided by deliberate design—rational planning to achieve social and economic goals deemed worthy by the planning authority. In contrast, the market system harnesses self-interest to promote outcomes that may transcend any individual's own immediate plans or objectives. The enduring metaphor for the market process is the invisible hand. Adam Smith gave us this metaphor in those most familiar (and eloquent) passages from the *Wealth of Nations:* "It is not from the benevolence of the butcher, the brewer or the baker that we expect our dinner, but from their regard to their own interest," for the individual "intends only his own gain, and he is, in this, as in many cases, led by an invisible hand to promote an end which was no part of his intention" ([1776] 1937, 14). Whether Smith actually understood the invisible hand in purely metaphorical terms or somehow more literally is an interesting question.[9] In any case, most economists today invoke the invisible hand metaphorically to describe how a decentralized system of individual economic agents interacting in various modes of cooperation and competition results not in chaos, but in order and coordination.

The interactive processes (the invisible hand) by which decentralized markets function without the guiding intelligence of a planning authority suggest that economic planning (the *visible* hand) is unnecessary. The invisible hand in itself, however,

9. Several new interpretations of Smith's invisible hand have appeared in the economics literature recently. See, for example, Vaughn 1989; Ahmed 1990; Rothchild 1994; Khalil 2000; Minowitz 2004; and Denis 2005.

does not explain fully why market-oriented economies have performed better than centrally planned economies. Although it is important to understand how the market is guided as "by an invisible hand," it is also important to understand why planning has failed to deliver on its promise to do *better* than a decentralized market system that, after all, is far from perfect and fails in various ways and degrees. An important reason for planning's failure relative to the market is found in the phenomenon of the vox populi, the "wisdom of crowds."

Francis Galton, in his 1907 *Nature* article "Vox Populi," was one of the earliest writers to document the "wisdom of crowds." He enlisted 787 participants to guess the weight of an ox at the West of England Fat Stock and Poultry Exhibition in Plymouth. Some of the competitors were experts, such as butchers and farmers, and others were men "off the street" with no special knowledge about the matter at hand. Galton calculated the average estimate—the vox populi—and found it to be almost perfect: 1,197 pounds, compared to the actual weight of 1,198 pounds. Galton's real purpose, according to James Surowiecki (2004), was nothing so superficial as discovering the weight of an ox. He had hoped that by demonstrating that the wisdom of the crowd is inferior to that of "experts," he would bolster the argument that the average voter in a democratic election is incapable of making an informed judgment. It would be an understatement to say that the crowd did better in Galton's experiment than he expected. (Surowiecki does not report whether Galton was persuaded by his findings to adopt a more democratic point of view.)

Although the vox populi phenomenon is closely related to the invisible hand, the two are not quite the same. Consider a noneconomic problem situation: the design of a network of sidewalks leading to and from various points at a newly constructed building. One approach to laying out such a network is simply not to design the thing at all. In this case, the *invisible-hand* question is, Will pedestrians over time wear paths that establish a functional overall pattern of walkways, even though each individual is concerned only with reaching his own destination? Another approach is to employ someone with expertise in the matter at hand—a landscape architect perhaps—in which case the vox populi question becomes, Will the expert do better than the pedestrians?

In economics, the invisible hand symbolizes the process by which market participants are guided, in large part by market prices, to coordinate their activities with one another and ultimately to serve purposes beyond their own self-interested concerns. The vox populi has to do with the nature of the information contained in those market prices and with whether prices automatically embody *better* information than the planning authorities can assemble deliberately. My discussion turns eventually to selective credit control as an illustration of collectivist planning. In that instance, the invisible-hand question asks, Will self-interested participants in competitive capital markets effectively allocate credit to worthy firms and industries? The vox populi question would be, Can a national investment committee *more effectively* allocate credit from the elevated perspective of a central planning authority? If the planning

approach tacitly dismisses the invisible-hand question, it fairly begs the vox populi question. The latter arises in economics whenever the sphere of government decision making expands into what was the sphere of laissez-faire economics—that is, when planning replaces the market.

The sorts of vox populi questions posed here are being answered today in the negative—not for the first time, but for reasons that have been formally explored for the first time only recently. The past few years have seen the study of the "wisdom of crowds" take a quantum leap forward. I now proceed to offer an intuitive interpretation of that research.

Diversity and the Wisdom of the Crowd: Two Models

The vox populi phenomenon has been documented many times.[10] A classic study was Treynor's (1987) jelly-beans-in-the-jar experiment, in which fifty-six students estimated the number of jelly beans in a large glass container. The jar actually contained 850 beans; the group's average estimate was 871, and only one of the fifty-six students made a better guess than that. One of the earliest studies of group intelligence (Knight 1921) demonstrated that groups could guess the temperature of the room they occupied with amazing accuracy. These early studies were essentially just statistical analyses of participants' responses to simple questions. In these bean-in-the-jar types of experiments, extremely inaccurate estimates tend to cancel each other out, guaranteeing that the average will be fairly accurate. As Surowiecki puts it, "Each person's guess, you might say, has two components: information and error. Subtract the error, and you're left with the information" (2004, 10). (We shall see that if the group is large enough and sufficiently diverse, the collective information "you're left with" is remarkably complete.)

Researchers have more recently examined the vox populi phenomenon (without referring to it as such) as it appears in a variety of contexts, from Google's PageRank algorithm (Brin and Page 1998) to the Hollywood Stock Exchange (Pennock et al. 2000) and the well-known Iowa Electronic Markets project (Pennock and Wellman 1997). These and other such "applied" studies are informative and more sophisticated than the earliest vox populi research. The focus of my present review is somewhat narrower: I consider "basic" rather than "applied" research because it establishes new theoretical understanding. It is characterized by a high degree of formalism and the use of computer simulations to provide the "data" for its conclusions. This research develops a type of "artificial agent" model similar in some respects to artificial agent models in macroeconomics (Sargent 1993), game theory (Kalai and Lehrer 1995), and political economy (Kollman et al. 1992), but it differs from these models by allowing its agents to have differing perspectives, capabilities, experiences, and even

10. Lorge and colleagues (1958) present an informative survey of early research on the vox populi phenomenon.

methods of problem solving. Thus, it brings an element of realism to a highly abstract field of study because the real world is populated by persons who differ in all of these ways. More important, it isolates the source of the collective wisdom in group problem solving and reveals it to be diversity. The models demonstrate that diversity "*truly* enlarges the set of all possible ways of solving a problem" (Hong and Page 1998b, 3).

The new research also differs from earlier vox populi studies by modeling an information environment similar to that described by Hayek, in which knowledge is fragmented, scattered, and not given to any one entity in its entirety. In this sort of environment, diversity most effectively "enlarges the set of all possible ways of solving a problem."

A Maze of Rules

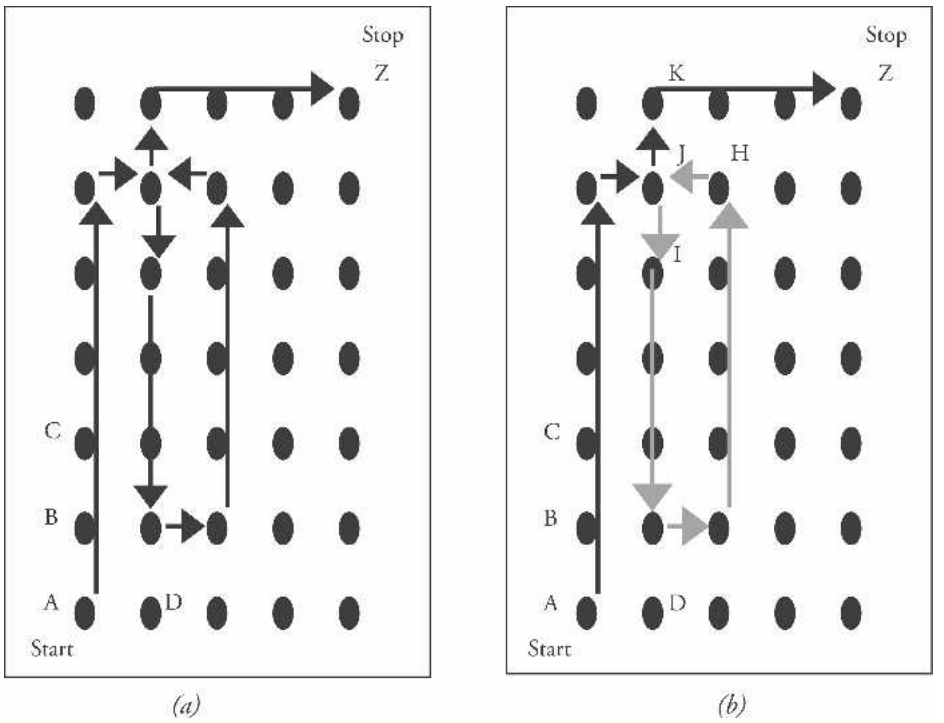
Two research efforts best exemplify this new scholarship—the questions it asks, the methods it employs, and the conclusions it reaches.[11] The principal researchers are Norman L. Johnson (1998, 1999, 2000) and, in a closely related research effort, Lu Hong and Scott Page (1998a, 1998b, 2001, 2004). I begin the review with Johnson, a theoretical physicist with the Los Alamos National Laboratory. He conducts computer simulations in which "virtual agents" make their way through mazes, as in Figures 1a and 1b, the object being to find the shortest path to the destination, the terminal node.[12] The first time through, these agents move from one node to the next as directed by a set of simple "learning rules." The next time through, they apply information gathered during the first trip, in accordance with specific "application rules." Not surprisingly, agents become better at navigating through the maze as they learn more about it from experience.

Consider the maze depicted in Figure 1a. The learning rules encoded into the simulation instruct an agent to choose randomly between nodes B and D, and then assign values to each of the linkages. Specifically, the learning rules require that the chosen link (A to B) be assigned a value of 1 and the reciprocal linkage (B to A) a lesser value (say, 0.1). The other link (A to D) is set equal to 0. From node B the agent then proceeds to node C, for example, and assigns that linkage a higher value than the reciprocal linkage, and so on. In this manner, the agent makes its way through the maze until it happens to arrive, finally, at the terminal node Z. Assigning values to linkages in this manner is analogous to putting down breadcrumbs, *always leaving more breadcrumbs at the most recently chosen node*. In the second time through the

11. What follows is neither a comprehensive nor a critical review of the literature. If oversimplification and intuitive interpretation have created any inaccuracies or misrepresentations, these mistakes are solely my responsibility, and the researchers under discussion should not be blamed.

12. My discussion of Johnson's research refers to his 1998 publication *Collective Problem Solving: Functionality beyond the Individual* unless otherwise noted. Although his other articles (1999, 2000) cover much of the same ground, the 1998 report is by far his most informative and comprehensive single publication.

Figure 1
Path Solutions



Source: Johnson 1998.

maze, the agent follows application rules, which essentially instruct it to choose linkages with the highest values. To continue with the breadcrumb analogy, at each node the agent proceeds to the adjoining node that has the most breadcrumbs.

Figure 1b illustrates how the agent can remove an extraneous loop during the application phase and thereby shorten the route by nine moves. Because the learning rules assign greater values to more recently chosen linkages, an agent at node J will choose node K over nodes I and H, avoiding the extraneous loop. In computer simulations, the improvement in performance in the application phase proved to be remarkable. In one simulation, the average agent took 34.3 moves to find the exit the first time through, but only 12.8 moves during the application stage (Johnson 1998, 14). Had the loop not returned through node J, the agent would not be in a position to choose between I and K and could not improve over the original learning path. (No new learning occurs during the application phase.) Although nothing guarantees that a loop of this sort will develop in the first place, Johnson reports that learning paths in computer simulations actually tended to be complicated and turned back on themselves many times.

Suppose that an individual agent were sent through the learning phase repeatedly before entering the application phase. Because of the randomness of learning-rule decisions, it is very likely that each trip would produce a different learning path and therefore a different pattern of breadcrumbs. Many different nodes would eventually be visited and left with "breadcrumb values." In this case, the information gathered in the learning phase would be more complete because more of the maze had been explored and mapped with breadcrumbs. The shorter route discovered via application rules after many learning trips would presumably be better (that is, require fewer moves) than the route discovered after only one trip through in the learning phase. Formally speaking, the same thing happens when many different agents are sent through the maze at the same time, assuming they all play by the same learning rules. Each starts from the same position, but through random moves takes a path through the maze that is likely to be somewhat different from the paths that others take. As in the individual experiment, the application rules yield a shortened path to the exit. Johnson calculated the group's collective solution in a simulation with one hundred agents navigating the type of maze depicted here and discovered that the group's path was only 9 moves (1998, 23). This path was not merely shorter than the path of the individuals' average, 12.8 moves; *it was the shortest path possible*. In other simulations, Johnson found that the collective solution is always better than the individuals' average when twenty or more individuals constitute the collective. This difference in performance is Johnson's definition of *collective advantage*.

Experiential diversity of the kind just discussed is important for producing a collective advantage, but another type of experiential diversity—whether agents are "novice" or "established"—also plays a role in generating the collective advantage. Johnson defines "novice" problem solvers as those with little experience in solving a problem, whereas "established" agents have solved the same problem many times. Paradoxically, groups consisting of both novice and experienced agents outperform homogeneous groups of only experienced agents. According to Johnson, this surprising result occurs because experienced performers are actually less adept than novices at recovering from trouble. In the maze experiments, the individual agent eliminates extraneous loops and thereby shortens the path to the exit during the application phase. Johnson posits that the information contained in these rejected loops would be "less reinforced" (1998, 18) and eventually lost as the individual repeatedly solved the same maze. But this same information—that is, knowledge of this "forgotten" part of the maze—might still be retained by the novice agent. If so, the addition of novice problem solvers to a group of experienced agents might enable the recovery of knowledge that had been "forgotten" by the experienced agents. In two situations, this knowledge can be very useful: when there is "noise" and when there is "loss" of information.

Noise is the random replacement of valid information with false information; *loss* is the reduction of information. In the breadcrumb analogy, noise would be equivalent to a breeze scattering breadcrumbs from their "correct" positions—that is, from

where they were put down during the learning phase. Loss would occur if the breadcrumbs were blown away completely. Noise and loss in Johnson's simulations correspond generally (if perhaps imperfectly) to the existence in economics of "externalities" or other forms of market failure when important economic information is misrepresented or not contained at all in market prices.

Noise leads individual agents to parts of the maze for which they have no experience from the learning phase. The *collective* would not be misled, however, if knowledge of the "forgotten" parts of the maze (forgotten, that is, to experienced agents) were "recovered" with the inclusion of novice agents. Computer simulations confirm this condition to be the case. Johnson discovered that noise *did* degrade the performance of individuals (both novice and experienced), but *did not* diminish the performance of large collectives containing both novice and experienced agents (1998, 24–25). At very high magnitudes of noise, a slight degradation of collective performance occurred among small collectives, but no degradation occurred among collectives with larger numbers of individuals. Large collectives of experienced agents showed almost no loss of performance in the presence of noise. However, small collectives of experienced agents did not perform as well as small collectives of novice agents. Taken together, these results indicate that diversity assists the collective performance. Johnson concludes that collectives containing both novice and experienced agents would be optimal in the presence of noise. Modeling the consequences of "loss" is more complicated, but the inclusion of novice agents helps to overcome this problem as well, much as it does for noise (1998, 25–28).

These results run counter to the reasonable expectation that noise and loss should degrade the group's performance. To the contrary, the collective advantage proves to be remarkably insensitive to both types of disturbances. These results have profound implications for Hayek's defense of the market system. One might respond to Hayek with the argument that the market would be very efficient indeed if it worked in reality as it does in theory. However, market failure—specifically the occurrence of "noise" and "loss" in the market's handling of economic information—is a reality, and to compare the market *in theory* with planning *in practice* is neither reasonable nor fair. In fact, Hayek did not argue that markets function perfectly.[13] Johnson's results suggest, however, that taking issue with Hayek on "market imperfection" grounds is not a strong argument anyway because *noise and loss do not degrade the collective advantage*. The point is not that these types of market failure never happen in reality, but that the vox populi remains valid even when they do.

Experiential diversity is beneficial in producing a collective advantage, but diversity of performance capability also enhances the "wisdom of crowds." The agent's problem-solving capability in Johnson's model is formally determined by the learning

13. Hayek was explicit in this regard: "Of course, these [price] adjustments are probably never 'perfect' in the sense in which the economist conceives of them in his equilibrium analysis" (1948, 87).

rules that the agent follows. To this point, we have considered results when all agents follow the same learning rules and therefore have identical problem-solving ability (although not equal levels of experience). Johnson has also incorporated diversity of ability in various simulations by giving different agents different learning rules to follow. He discovered that narrowing the distribution of performance—that is, creating a more homogeneous group of agents in terms of ability—reduces the collective advantage (1998, 28–30). In fact, a homogeneous group of average performers showed almost no collective advantage. A homogenous group of extremely high performers did outperform the homogeneous group of average performers, but this difference does not necessarily mean what it might seem to mean. Johnson also found that a homogeneous group of relatively *poor* performers also did better than the average group. Perhaps most significant, however, *a heterogeneous group outperformed all homogeneous groups, even the homogeneous group containing only the most capable problem solvers.* Johnson himself deems these results to be "the most interesting and initially the most counter-intuitive" among any of his studies to date (1998, 28). He concludes that the dynamics of the model "are not simply a linear imposition of information from the individuals. There appears to be a complex interaction that requires diversity of performance, when the experiential diversity is relatively constant" (29).

Johnson also performed simulations with mazes of varying degrees of complexity (1998, 30–31). He found that a very simple maze presents a trivial problem for most individuals, and no advantage is realized with a collective solution; the collective advantage emerges in more complex mazes. However, the collective advantage begins to degrade with extremely complicated mazes unless the collective also becomes larger and contains a higher number of more-capable performers (but not fewer less-capable performers). Essentially, the collective must be both large and diverse in order to find optimal solutions to extremely difficult problems.

Johnson's approach does not allow direct interaction among agents. This lack of interaction might seem to be a weakness of the model because it eliminates from consideration many modes of behavior, both competitive and cooperative. But Johnson is concerned to isolate the vox populi phenomenon from any other sort of collective advantage that might result from cooperation or other game-theoretic phenomena. Typical game-theory models, such as the Prisoner's Dilemma, allow agents to modify their own behavior based on their assumptions about how others will behave. The functionality of a collective in the game-theoretic context thus involves more than the vox populi phenomenon. The vast body of game-theory literature lies beyond the scope of this discussion, although it is certainly tangential to it.

My simplified interpretation of Johnson's models omits discussion of various permutations and variations involved in the many simulations he has reported. Nonetheless, his findings boil down to a simple conclusion: the collective, the "crowd," demonstrates prodigious problem-solving ability if the population of problem solvers is large and, most important, diverse.

Perspectives and Heuristics

Economist Lu Hong has teamed with political scientist Scott Page in research similar to Johnson's. Their model is slightly different, however, in that it characterizes each problem solver in terms of a "perspective/heuristic pair." A *perspective* is an internal language for representing a problem, an encoding; a *heuristic* is a rule (or rules) one applies in searching for a solution. Differences in perspective can be interpreted as either neurological phenomena—that is, as different ways our brains perceive and process information—or what Hong and Page term *metaphorical* phenomena, which reflect differences in training and experience. One might expect persons from radically differing cultures, for example, to see things from different perspectives. Heuristics are essentially methodological, the ways in which persons go about solving a problem—their "bag of tricks," as the authors put it (1998b, 9). Different heuristics imply different formal methods of analysis. Thus, an economist, a psychologist, and a priest might bring very different methods, or bags of tricks, to their analysis of the same problem. The solution one identifies depends on the interplay of perspectives and heuristics.[14] Problem solvers may differ along either dimension, with the two dimensions serving as sources of diversity in this model. The group collectively has an advantage over a single problem solver because many different perspective/heuristic pairs lead to the consideration of more potential solutions and therefore to a better final solution.

Hong and Page illustrate one version of their collective decision-making process with the problem of selecting among various public-works projects (1998b, 10–12). A team of city council members considers three projects: p_1, p_2, and p_3. The eight possible solutions and their values are given in Table 1.[15]

An omniscient observer would know that x_6 has the highest value, but no participant knows, going in, which solution is best. Rather, each attempts to find the highest-value solution according to his perspective/heuristic pair.[16] City council member 1 (M1) begins his deliberations at x_0 (fund no projects). Assume that M1 knows three methods of analysis, which he proceeds to apply sequentially. Applying the first method results in changing the decision about p_1 (only): it gets funded. This

14. This interplay of perspective and heuristic implies something close but not equivalent to the economic notion of entrepreneurship.

15. These solution values have no particular meaning other than as a comparative metric for ranking the various outcomes.

16. Hong and Page formally represent perspectives as binary string sets and represent heuristics as methods that result in "flipping" one or more digits in the string. For example, one agent's string set (perspective) might be represented as 011, which corresponds to funding the second and third projects, but not funding the first. The agent's first "trick" might be to "flip" the first and third numerals simultaneously, resulting in 110—funding the first and second projects, but not the third. The agent proceeds through his bag of tricks, or employs his methods of analysis, flipping numerals accordingly until he can find no better solution. A different agent might start out with different perspectives, in which case 011 might correspond to funding the first project, but not the second and third. This agent's tricks might be different as well. He might begin by flipping, say, only the first digit and, unlike the other agent, might never flip the first and third numerals simultaneously.

Table 1
Possible Solutions

Solution		Value
x_0	fund none	0
x_1	fund p_1 only	40
x_2	fund p_2 only	20
x_3	fund p_3 only	30
x_4	fund p_1 and p_2	60
x_5	fund p_1 and p_3	50
x_6	fund p_2 and p_3	70
x_7	fund all three	10

Source: Hong and Page 1998b.

solution is represented by x_1 in table 1, which has a value of 40—an improvement over the original position. He then applies his next method of analysis to x_1 and decides on solution x_4, which calls for funding p_2 as well as p_1. This solution is yet a further improvement (60) and therefore becomes the new status quo. When he applies his method to x_4, the result yields no improvement. Therefore, x_4 remains the status quo. He then applies each of his other two methods to x_4, but still finds no reason to change his mind, given his perspective and methods of analysis. Thus, x_4 is a local maximum for M1; he gets "stuck" at that point.

Suppose that city council member 2 (M2) picks up where M1 got stuck. Obviously, if M2 has the same perspective/heuristic pair as M1, he will not be able to find an improvement. But assume that M2's heuristics, or bag of tricks, are somewhat different from M1's. (Perhaps M1 is knowledgeable in the political aspects of public administration, but M2 is trained as an accountant.) M2 employs certain methods of analysis unknown or unavailable to M1. What happens when M2 starts where M1 stopped? Suppose that in applying his first "trick," M2 gets the same result (that is, reaches the same conclusion) as M1. But then he applies his second trick and reaches the decision to fund p_2 and p_3, with a value of 70. This choice then becomes the new status quo because it has greater value than x_4. Because M2 brings a different perspective/heuristic pair to the problem, he can improve on M1's solution. Diversity thus leads to a better outcome.

Various computational models developed by Hong and Page and their purely formal mathematical solutions demonstrate the importance of diversity (1998a, 7–12). The general procedure in all these models is to endow each virtual agent with a perspective/heuristic pair and to "instruct" it all to search for the highest value among many alternative solutions distributed throughout the problem domain. Search continues until no agent can find a better solution—that is, until it has been demonstrated that the group's best solution lies within the intersection of the indi-

Table 2
Comparative Performances

Approach	Value
Individuals	8.1
Best 20	9.5
Worst 20	6.7
Group Random	14.3
Group Best 20	14.2
Group Worst 20	13.8

Source: Hong and Page 1998a, 8.

vidual agents' local optima.[17] The advantages of diversity are clearly seen in results of experiments in which agents are endowed with differing perspective/heuristic pairs. Table 2 presents results of a simulation involving collections of the best problem solvers, the worst problem solvers, and a random group of problem solvers.[18] Higher values represent better solutions.

The results here are remarkable. They indicate that a group of relatively ineffective problem solvers (Group Worst 20) can do almost as well collectively as a group of very capable agents (Group Best 20) and better than the average of the best problem solvers acting individually (Best 20). Furthermore, a diverse group acting collectively (Group Random) does better than more capable agents working either individually (Best 20) or collectively (Group Best 20). In another set of simulations, problem solvers with identical perspectives employ different heuristics, as in my public-works illustration (Hong and Page 1998a, 8–12). In these cases diversity is generated exclusively by differing heuristics, yet the results are similar: random groups of problem solvers consistently outperform groups containing only the best performers. In simulations involving groups of ten and twenty agents, the best problem solvers *always* failed to perform as well as the random group.

More recent research by Hong and Page (2004) reconfirm their previous results. Agents in this model encoded n solutions as n points on a circle from 1 to n clockwise. An agent with the heuristic (1, 4, 11), starting at point 194, for example, would first evaluate point 195 (194 + 1) and compare it with 194. If point 194 were higher, the agent would then consider point 198 (194 + 4) and compare it with point 194, and so on. The agent continues in this manner until none of the moves locates a higher

17. The agents need not proceed sequentially, as they do in my public-works illustration. The generalized mathematical version of the model does not constrain agents to sequential search.

18. Hong and Page demonstrate that different perspective/heuristic pairs are more "productive" than others and therefore would be expected to find higher-valued solutions. The best (worst) agents are those who, working alone, would have the highest (lowest) expected values from search. It is not generally the case, as these results indicate, that a single problem solver is able to find the optimal result or to match the group's performance.

Table 3
Performance and Diversity

Group Composition	Performance	Diversity
Ten Best Agents	92.56	70.98
Ten Random Agents	94.53	90.99
Twenty Best Agents	93.78	74.95
Twenty Random Agents	94.72	91.46

Source: Hong and Page 2004.

value. The performance of an agent is measured as the value of the expected stopping point, assuming that each point is equally likely to be the starting point. For the group, the process is sequential, as in previous models; that is, one agent picks up where another stops. The performance of the collective is then defined as the expected value of the stopping points. Results of numerous computer simulations based on this framework indicate that a *random* set of agents drawn from a large pool of limited-ability performers typically does better than a *chosen set of the best performers* from that same set. Table 3 summarizes Hong and Page's findings.

Like Johnson before them, Hong and Page explain their results in terms of diversity. The more successful collectives of problem solvers are characterized by greater degree of diversity. "With a large population of agents, the first group, although its members have more ability, is less diverse. To put it succinctly, diversity trumps ability" (2004, 4).

As with the review of Johnson, this discussion of Hong and Page is but a "Cliffs Notes" conspectus of a body of research that is extraordinarily rigorous, sophisticated, subtle, and incisive. Yet the approach these researchers take, for all its formal complexity, is logically simple and intuitively appealing. Their conclusions reduce simply to the idea that diversity is the key to effective problem solving: "The main results of this paper rely on straightforward logic. If people are bounded, they probably differ in how they solve difficult, i.e., multi-dimensional problems. . . . Being boundedly rational only stifles good decisions if we are boundedly rational in the same way. If the best problem solvers tend to think about a problem similarly, then it stands to reason that as a group they may not be very effective. Random groups may be better owing to their diversity" (Hong and Page 1998a, 16–17).

Although the authors reviewed here have not explicitly related their models to Hayek's thinking, the relevance of this recent work to Hayek's ideas, particularly to his "dispersion of knowledge" argument, is rather obvious. The "breadcrumb" values in Johnson's maze experiments function similarly to market prices in the economy. Both assemble fragmented knowledge and are comprehensive in scope, "not because any of [a market economy's] members survey the whole field, but because their limited individual fields of vision sufficiently overlap." Hayek's words, repeated here at the risk of overemphasis, describe almost exactly the collective solution in Johnson's maze

simulations: the overlapping of breadcrumb trails left by numerous agents surveying different parts of the maze. Generally speaking, Hayek, Johnson, and Hong and Page consider essentially the same problem situation and reach a common conclusion. In both the real world of economic activity and the virtual reality of computer simulation, "agents" must find solutions to problems in an environment where the information needed to discover the optimal solution is fragmented and scattered throughout the problem domain.[19] No single agent possesses more than a small part of this information, and none has the capacity to acquire more than a small part in its "raw" or explicit form. Yet collectively all the agents "know enough" to reach an optimal solution, especially if the collective contains individuals sufficiently different from one another in their experiences, perspectives, heuristics, and so on. The essence of the task before them is to discover the collective wisdom, which in these circumstances is superior to the judgment of small groups, even small groups of experts. The answers to the problems they confront are heard in the vox populi. [20]

Conclusions and Further Observations

More than seventy years ago Hayek first put forward his thesis that markets work better than central planning because markets make the best use of knowledge. Now, a new research program has appeared and come to a "Hayekian" conclusion of its own: in situations where information is decentralized, the collective wisdom, the vox populi, is demonstrably superior to the judgment of experts alone.

Even if the new research yields insights that support Hayek's critique of collectivist economic planning, however, one might still question whether the whole debate over central planning versus markets has any relevance for a post-USSR world. Will central planning ever come to the United States or other market-oriented industrial nations? Those who would dismiss the debate as irrelevant or passé would do well to consider that full-blown central planning of the old Soviet style may not be necessary for collectivism to come to modern capitalistic economies. Economist William F.

19. Hayek emphasized also that economic problems arise as a consequence of change (1948, 81–82). In the new studies, the parameters of the problem domain do not change during the search for a solution; the maze, for example, does not reconfigure itself in the middle of the agents' search for an optimal path to the exit. Of course, the new studies do not deny that new problem situations or different permutations of previous problems are constantly presenting themselves in the real world. The collective advantage would presumably emerge each time a different problem situation "comes along." More fundamentally, to deny the fact of change would undermine the very raison d'être of the research effort: if things continue as before, there are no new problem domains to explore, no new solutions to be found, and no reason to study the manner in which a collective goes about finding them. Likewise in economics, if nothing ever changes, there would be little reason to study the informational function of prices.

20. The problems that the agents confront, as described here, are not entrepreneurial problems. Entrepreneurship involves a kind of discovery not really captured in the models presented. Entrepreneurial problem solving involves, among other things, creative thought on the individual's part, which is quite different from the "wisdom of the crowd." In a sense, entrepreneurs create new solutions; they do not merely find the highest-valued option that already exists within a closed set of possible solutions. The vox populi is not, therefore, the same thing as entrepreneurial insight.

Campbell (1980) argues, for example, that the United States may embrace a different kind of collectivist planning in the form of selective credit control.[21] The intellectual roots of this type of collectivism go back at least to Saint-Simon, who confidently expected that "a central body of management, able to survey the large fields of social economy from a more elevated point of view, will regulate it for the benefit of the whole society, will be able to put the means of production into suitable hands. . . . Institutions already exist which have assumed as part of their task a certain organization of economic labor: the banks" (qtd. in Garvy 1972, 255). V. I. Lenin maintained that "without big banks, socialism would be impossible. The big banks are the 'state apparatus' which we need to bring about socialism, and which we take ready-made from capitalism" (qtd. in Garvy 1972, 252).

Selective credit control shows no signs of receding into history with other elements of socialism's collectivist planning system.[22] It survives in the recommendations of such prominent modern-day economists as Lester Thurow:

> We do not need central economic planning in the sense of an agency that tries to make all economic decisions, but we do need the national equivalent of a corporate investment committee to redirect investment flows from our "sunset" industries to our "sunrise" industries. . . . For most of our industrial competitors the central bank plays an important role in allocating investment funds. . . . A national bank could be regarded as a competitor with private banks or it could work through the private banks as it does in Japan. It certainly represents more government in the mixed economy, but the time has come to recognize that if we are going to compete with some of our more successful industrial neighbors, we are going to have to change the way we have been doing things. (1971, 95–96)

Thurow is obviously convinced that national investment decisions in the United States must be entrusted to the judgment of experts lest the country fall behind other industrial nations in economic growth and development. We have also heard calls more recently for credit control in the name of environmental responsibility. For example, D'Arista and Boyce (2002) propose the establishment of a U.S. Environmental Finance Authority, whose purpose would be to channel credit to environ-

21. My discussion here borrows much from Campbell 1980.

22. American politicians have advanced numerous proposals for credit control, most of which have been defeated, but the 91st Congress passed the Credit Control Act of 1969, which declares that "[w]henever the President determines that such action is necessary or appropriate for the purpose of preventing or controlling inflation . . . the President may authorize the [Federal Reserve] Board to regulate any or all extension of credit" (Public Law 91–151, December 23, 1969, Title II, Sec. 205, p. S2577). A president who is otherwise averse to imposing explicit economic regulations, such as trade barriers, subsidies, or wage-and price controls, might be tempted to apply selective credit controls ostensibly for the purpose of fighting inflation, but really for any number of other reasons. For a detailed analysis of various credit controls and the arguments for and against them, see Yeager 1977.

mentally beneficial projects and policies. In every instance—past, present, or future—the presumption underlying credit-control proposals is that the "elevated" perspective of suitably chosen experts would be superior to the collective wisdom expressed in the financial markets. This presumption is the very antithesis of the vox populi, an absolute rejection of the wisdom of the crowd.

Although selective credit control is not the only manifestation of the collectivist impulse given voice in public debate in the post-Soviet world, it may well be the form most likely to prevail eventually in market-oriented nations such as the United States because it is also one of the most insidious forms. In Campbell's words, "For collectivism to come to the United States all we have to do is sit back and let good men allocate credit" (1980, 5). The new research into the wisdom of crowds has much to contribute to future debate on this important issue.

The new research may also contribute indirectly to the study of "endogenous" models of economic growth and development. Long-term growth is determined within the model ("endogenously"), rather than by forces impinging from without.[23] Endogenous factors may include the size of government, antitrust regulation, patent laws, the degree of market competition in various sectors of the economy, education, religion, freedom, and respect for the rule of law, among others.[24] Without referring to growth models as such, Hong and Page suggest that diversity is an important endogenous source of progress in market-oriented societies: "The diversity of human perspectives and heuristics implies that no local and non global optimum should be sustainable. Someone eventually builds a better mousetrap, not because that person is smarter . . . but because that person sees or approaches the problem differently. . . . [E]ventually any improvement should either come to market or become obsolete" (1998a, 17). Hong and Page hint at an evolutionary economic process that depends crucially on diversity, as does the process of evolution in biology. As the economies of Western countries have developed, economic enterprises of all sorts have evolved in adaptive response to ever-changing technological, financial, and political environments. The result is a striking diversity in many areas of commerce, finance, research, and society in general. Rosenberg and Birdzell are explicit about the importance of diversity in economic growth and development: "This diversity in the forms of economic life, like the diversity in biosystems, is important not only for its own sake but because it is an earmark of successful adaptation and full utilization of resources available" (1986, 33).

Economists have developed empirical measures of such sociological factors as

23. Barrow (1997) provides an excellent overview of endogenous growth theory and related empirical work.

24. Romer enumerates several endogenous determinants of growth, including "tax subsidies for private research, antitrust exemptions for research joint ventures, the activities of multinational firms, the effects of government procurement, the feedback between trade policy and innovation, the scope of protection for intellectual property rights, the links between private firms and selecting the research areas that receive public support, and the costs and benefits of an explicit government-led technology policy" (1994, 20–21).

political and economic freedom—the Heritage Freedom Index, for example. Perhaps an analogous index of diversity or a set of diversity indexes for various aspects of a nation's economy would enrich the study of endogenous economic growth and development. Diversity as such has not been formally included in such studies to date, but perhaps it should be. Economic growth involves adaptive change, which is a form of problem solving.[25] The role of diversity in this type of problem solving has long been recognized.

Finally, it may occur to some readers that the case made here for the vox populi is self-contradictory because it relies on the judgment of experts to discredit "the judgment of experts." Readers must decide for themselves how much importance to attach to the new research of the experts whose work I have reviewed, with their mathematical solutions and computer simulations. The disintegration of the Soviet Union, however, was not a computer simulation, but an actual historical event—and, in a most emphatic way, an expression of the vox populi.

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25. This process is somewhat more creative—more entrepreneurial—than the problem solving described in the models of diversity reviewed here.

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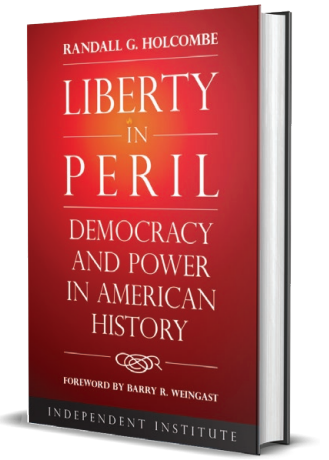

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