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# *Resourceship*: An Austrian theory of mineral resources

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**Abstract** Economists inside and outside of the Austrian-school tradition have formulated a subjectivist theory of mineral resources. While von Mises (1940) presented a rudimentary theory, institutionalist Zimmermann (1933 and after) provided an in-depth mind-centered approach distinct from the objective, neoclassical theory for minerals developed by Jevons (1865, 1866), Gray (1913), and Hotelling (1931). A full-fledged Austrian theory identifies the fixity/depletionism view of minerals as incompatible with entrepreneurship. Mineral *resourceship*, praxeologically akin to manufacturing, or the making of capital goods, demotes the distinction between depletable and nondepletable resources for the sciences of human action. Instead of nonreproducibility, the interplay of geography and institutions becomes the locus of mineral-resource theory, given the nonuniform distribution of deposits. An Austrian-institutional theory is more robust for explaining changes in mineral-resource scarcity than neoclassical depletionism, and offers a wide research agenda for current debates over resource production, usage, and future availability.

**Keywords** Austrian economics · Conservation theory · Harold Hotelling · Institutional economics · Mineral resources · Natural resources · Erich Zimmermann

**JEL Codes** M13 · Q31 · Q41 · B52 · B53

F.A. Hayek (1952, p. 52) stated, "It is probably no exaggeration to say that every important advance in economic theory during the last hundred years was a further step in the consistent application of subjectivism." Hayek's insight rings true for mineral-resource economics, where an economist outside of the Austrian tradition, Erich Zimmermann, developed a subjectivist (mind-centered) theory in the 1930s for understanding the nature of so-called depletable (or nonreproducible)

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minerals and explaining a paradox of economic phenomena—the expanding supply of believed-to-be-wasting natural resources. Zimmermann's neglected beginning, when combined with brief insights provided by Ludwig von Mises, and the empirical work of M.A. Adelman regarding crude oil and Julian Simon regarding minerals in general, offers a theory of resource expansion that challenges the distinction between renewable and nonrenewable resources and the depletionist mindset it engenders. Location and the institutional environment—not chemical nonreproducibility—are important as the chief characteristics of minerals for social-science theory and applied economics.

This essay surveys the history of mineral-resource thought, identifying the precepts of a formalistic, objectivist theory that captured the mainstream of economics. The views of William Stanley Jevons in the nineteenth century, and L.C. Gray and Harold Hotelling in the first third of the twentieth century, are prominent. The perspective of Austrian-school economists are next considered, followed by the contributions of the institutionalist Erich Zimmermann, whose "functional theory" was more developed, and, in places, even more "Austrian." Using Zimmermann and Mises as the starting point, the essay presents key elements of a thoroughgoing subjectivist theory of mineral economics.

## 1 Birth of mineral economics: W. S. Jevons

Adam Smith's classical economics hardly differentiated mineral resources from other goods.[1] This changed with David Ricardo, who postulated that the cost of a fixed resource (land, metals) increased as it was exploited (Ricardo, 1821, Chaps. 2–3), creating declining profits and economic stagnation (Chap. 6). But it was not until 1865 that fears of exhaustion of a mineral resource became prominent in economics and the public mind. The work that marked the birth of mineral economics, William Stanley Jevons's *The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal Mines,* extrapolated the gloomy view of Thomas Robert Malthus from agriculture to minerals (Jevons, 1865, p. 149).

Malthus had questioned the continued availability of enough food to feed England's people. He predicted that, inevitably, the slow growth in food would be outrun by the country's surging population. Only some combination of "misery or vice" (Malthus, 1798, p. 17) or "moral constraint" (Malthus, 1803, p. 314) could reduce population to subsistence levels.[2]

A half-century later, Jevons likewise questioned the continued availability of affordable coal to fuel England's industrialism and global might. England occupied .04% of the world's land mass and had 2.5% of global population. Yet she produced over one-half of the world's annual output of coal for domestic use and exportation (Jevons, 1867, p. 26).

[1] *Mineral resources* should be distinguished from *natural resources*. Minerals such as crude oil and copper cannot be naturally or synthetically produced in signficant quantities, in a human time-frame, unlike natural resources such as agricultural products and water. In a natural-science sense, then, minerals are fixed and natural resources not.

[2] Malthus stated in the second edition that while he had "endeavored to soften some of the harshest conclusions of the first *Essay* . . . the conclusions of the former *Essay* will remain in full force" (Malthus, 1803, p. 3). Thus, Malthus was still a "Malthusian"—even if "moral constraint" is considered apart from "misery or vice."

Jevons sought to uncover "the necessary results of our present rapid multiplication [of demand] when brought into comparison with a fixed amount of material resources" (Jevons, 1865, p. 344). "For the present," he found, "our cheap supplies of coal, and our skill in its employment, and the freedom of our commerce with other wide lands, render us . . . out of the scope of Malthus' doctrine" (Jevons, 1865, p. 153). The good news stopped there. The "painful fact" was that "in the increasing depth and difficulty of coal mining we shall meet that vague, but inevitable boundary that will stop our progress" (Jevons, 1865, p. 154). Imports could not save the day, at least not the day in which England had a resource advantage; foreign coal was too distant, bulky, and heavy for transportation to substitute for domestic mining.

"To allow commerce to proceed until the course of civilization is weakened and overturned," Jevons warned, "is like killing the goose to get the golden egg." To arrest this future, he recommended an export tax to keep domestic coal at home and retiring the national debt to "compensat[e] posterity" (Jevons, 1865, pp. 329, 339).

Recognizing that "everything is a question of cost" (Jevons, 1865, p. 39), Jevons estimated the expense of mining different coal seams to construct what economists would later call a marginal cost curve. His assumed exponential demand growth of 3.5% per year was based on recent history and anticipated growth in population, industry, and international trade. Plotting supply and demand, Jevons calculated a "threatening" rise in fuel costs, "perhaps within a lifetime" and certainly within a century (Jevons, 1865, p. 215). England's advantage would be lost to other countries, such as the United States, which possessed far richer remaining coal deposits.

Jevons viewed the coal supply as a given quantity of resources, which would make production a bell curve of increasing, peaking, and then declining supply. This was constructed in geological terms by M. King Hubbert a century later, laying the basis for today's "peak oil" debate about whether the world's oil output has declined or will inevitably decline (Deffeyes, 2005).

The "coal panic" set off by Jevons turned out to be unfounded. Demand growth—3% between 1865 and 1880, 2% between 1881 and the turn of the century, and less than 1% thereafter—was far less than Jevons assumed. Interfuel substitution away from coal using other domestic fuels, something that he scarcely imagined, began with North Sea production of oil and gas in the late 1960s. Supply and demand meshed without exhibiting the depletion premium that Jevons had predicted. Instead of a "threatening" rise in coal costs, inflation-adjusted coal prices registered little change compared to the period that Jevons intensely studied (Mitchell, 1962, p. 483; Mitchell and Jones, 1971, p. 193).

England's coal production took a seemingly Jevonian turn around World War I, but this hardly vindicated his warnings of a half-century before. Pervasive government involvement in the domestic coal industry did what market forces had not done in the two prior centuries—reverse productivity and progress. Intervention began with labor-union mandates and continued with World War I nationalization (1917–1921), output restrictions and price supports, a second nationalization in 1946, and high tax-rates thereafter (Bradley, in press). Demand became stagnant during and after the Great Depression when rival fuels became available for industrial boilers and electricity generation. The coal market was far different and more nuanced than Jevons envisioned.

## 2 Neoclassical theory: Fixity and depletion

Between 1890 and 1920, resource conservation on the public domain became a national issue in the United States (Barnett and Morse, 1963, p. 44). President Theodore Roosevelt defined conservation as "the application of common sense to common problems for the common good" (Roosevelt, 1909, p. 3). This and other amorphous views of resource conservation would attract the interest of economists looking to better define the issues and inform public policy.

### 2.1 L. C. Gray (1913)

"The primary problem of conservation," wrote L. C. Gray in *The Quarterly Journal of Economics* in 1913, "is the determination of the proper rate of discount on the future with respect to the utilization of our natural resources" (Gray, 1913, p. 515). What might the discount rate be? Gray mentioned "'the crutch of common sense'" and called for "the economist to develop the theoretical basis upon which the solution of the ultimate problems of conservation must depend" (Gray, 1913, p. 519). Despite the open questions, Gray was convinced about present-period overproduction, an example of what economists would later call market failure. He championed "the creation of high values . . . through the socialization of those resources which are not used, and of those which, on account of their relative abundance, are being used in an exploitive way" (Gray, 1913, p. 517).

Gray's article, the beginning for twentieth-century conservation economics, contained three important and enduring precepts:

- *Fixed, objective supply*. "Minerals afford a tolerably clear-cut type of resources which are absolutely limited in supply and nonrestorable. It is necessary to make a definite choice between present and future. Normally, when once used, the supply is exhausted practically for all time.... This is absolutely true in the case of coal, petroleum, and natural gas" (Gray, 1913, p. 501).
- *Knowable supply*. "The nation has reached the point where it is possible to make a rough inventory of its mineral resources" (Gray, 1913, p. 497).
- *Aggregate intertemporal valuation*. "Society is confronted by the same choice that accumulation imposes on the individual: a choice between present satisfaction and future satisfaction" (Gray, 1913, p. 514).

Neoclassical economics would take Gray's cue and derive an objectivist theory of mineral resources that remains in the mainstream today.

### 2.2 Harold Hotelling (1931)

In a 1931 essay in *The Journal of Political Economy*, Hotelling applied differential calculus to derive the optimal allocation of a fixed resource over time. He began by noting that standard economic analysis was "plainly inadequate for an industry in which the indefinite maintenance of a steady rate of production is a physical impossibility, and which is therefore bound to decline" (Hotelling, 1931, p. 139).[3] A fixed, objective, knowable supply was the starting point for Hotelling, as it was for Jevons and Gray.

Hotelling showed that *if* the total resource base was known, fixed, and homogeneous; *if* capital investment was fixed; *if* the deposits were mined in order of (objectively known) least cost; *if* the most efficient extraction method were used; *if* resource prices were known in each time period—or just *if profit-maximizing automatons had perfect knowledge*—the resource would be produced and sold at a net price (marginal revenue minus marginal cost) that rose at the rate of interest over time. This price premium—a depletion value or *resource rent*, also called Hotelling rent, Hotelling's Rule, and user cost[4]—was a revenue stream that only a fixed (exhaustible) supply could command.

Hotelling's technical demonstration was ahead of its time. Mathematics was not yet a familiar language in economics (Hotelling's essay was originally rejected for publication for this reason [Arrow, p. 670]). Few if any mineral resources were evidencing increasing scarcity, leaving economists with little Hotelling-like empirical work to do. Minerals were not of particular interest to economists (or just about anyone else) until President Harry Truman created the President's Materials Policy Commission (Paley Commission) in 1951. The Commission's five-volume stocktaking on resources, published the next year, was followed by the creation of Resources for the Future (RFF), a think tank funded by the Ford Foundation. RFF economist Orris Herfindahl returned to Hotelling's work on the economics of depletion, in essays published in 1955, 1959, and 1967 (Brooks, 1974, pp. 35, 65, 130). Hotelling, meanwhile, best known within the economics profession for his essays on duopoly and welfare maximization, did not return to conservation economics (Arrow, 1998, p. 670). Still, Hotelling was "it" in mineral-resource theory. A rival theory developed by institutionalist Erich Zimmermann (discussed later) offered a more realistic approach to mineral resources but was only occasionally mentioned in the 1950s and 1960s and was forgotten thereafter.

## 2.3 Hotelling's Sophism

Hotelling's essay derived, in his words, a "golden mean" between "wholesale devastation of irreplaceable natural resources" and the conservationist paradox that "exploitation . . . can never be too slow for the public good" (Hotelling, 1931, p. 137). He rigorously proved an insight that was recognized from at least the time of Adam Smith: future scarcities impact present prices. But, there was poison in Hotelling's nectar. The assumptions giving rise to the depletion premium were exactly wrong for the real world that Hotelling aimed to inform (Brätland, 2000). So too was his assumption of perfect knowledge that banished entrepreneurship—or *resourceship* (McDonald, 1995)—in reference to minerals. Once Hotelling's "ideal state" (Hotelling, 1931, p. 146) was

[3] The incompatibility of wasting resources with equilibrium has also been noted by Austrian-school economists for the evenly rotating economy (von Mises, 1966, p. 643, footnote 10; Rothbard, 1962, p. 426).

[4] J. M. Keynes, following Alfred Marshall, several years later resurrected the "user cost" idea, stating, "In the case of raw materials the necessity of allowing for user cost is obvious" (Keynes, 1936, p. 75).

relaxed to allow for technological change, capital investment, resource substitution, and entrepreneurial adjustment, Hotelling's theory was inapplicable and misleading. The theory/practice divergence would haunt the profession when economists turned *en masse* to Hotelling's framework to explain the run-up in world oil prices in the 1970s.

Hotelling determined the profit-maximizing distribution of a fixed stock between time periods under a set of necessarily restrictive assumptions. On this score, his heralded theory advanced conservation theory—if only by creating a foil for reality. But, Hotelling made two errors in framing his analysis. First, he failed to explain why fixity/depletionism was misleading for real-world analysis and decision-making. Extraction firms and industries always face a "supply curve" where greater quantities can be produced or purchased. The quantities are just manufactured, as it were, below ground rather than in above-ground facilities.

Second, Hotelling linked his highly conditional analysis to the real-world debate over depletion, exhaustion, and public policy. He faulted *laissez-faire* for deviating from his derived optimality in production and pricing, stating: "There are in extractive industries discrepancies from our assumed conditions leading to particularly wasteful forms of exploitation which might well be regulated in the public interest" (Hotelling, 1931, p. 143). Yet Hotelling, so quick to recognize market failure, did not account for what economists now call government failure (Newcomb, 1885, p. 445; Coase, 1964, p. 195). As the long history of petroleum wellhead conservation regulation in the U.S. showed, government intervention was lacking information and was highly problematic in practice (Bradley, 1996, Chap. 4). Only an omniscient planner would know the specifics of supply, demand, cost, price, substitution, capital, interest rates, technology, and entrepreneurial alertness needed to implement the "optimal" solution, and political operatives could not be expected to implement the "solution" even if it were objectively discernible.

Mainstream economists have wanted to eat their cake and have it too with Hotelling's Rule. The scarcity premium, or user cost, is presented as a fact but then questioned because of an inability to empirically isolate the residual (Griffin and Steele, 1986, p. 73). This criticism can be taken a step further: Hotelling's scarcity premium is not causal because resource entrepreneurs have rarely if ever taken into account the neoclassical assumptions of known, aggregate fixity of supply. Instead, they take into account costs, prices, regulation, geopolitics, and other factors of short-to-medium-term disequilibrium. As an abstraction, user cost *does not exist* to be isolated and measured. Economic causality comes from purposeful human action.

Hotelling's essay, the most famous ever published in the history of mineral-resource economics, should have been titled "The Production and Distribution of Fixed Resources under Perfect Information," not "The Economics of Exhaustible Resources." Hotelling should have explained why the supply of mineral resources could increase, not decrease, with extraction. As it was, he specified a very special case, not a general one, a fact that economists learned the hard way when many fell into the depletionist trap of believing that the availability of mineral resources decreases over time.[5]

[5] As a reading of the first and last sections of his 1931 essay shows, Hotelling was keenly interested in real-world debates over mineral extraction and usage and meant to inform the real-world debate. His effort was not a theoretical exercise for its own sake. Given the use and misuse of his theory in light of empirical developments, Milton Friedman opined: "[Hotelling] was a great teacher and had a good deal of influence

Harold Hotelling was working in the neoclassical tradition just when economics was shedding its deductive, literary skin for a methodological formalism in which diagrams and mathematics substituted for spelling out the logic of real-world action. Hotelling's (1931) article spawned scores of others when the energy crisis hit in the 1970s. Yet when the dust cleared in the 1980s and 1990s, data-oriented energy economists found Hotelling's framework to be a *cul de sac*. "To explain the price of oil, we must discard all assumptions of a fixed stock and an inevitable long-run price rise and rule out nothing a priori," found Adelman. "Whether scarcity has been or is increasing is a question of fact" (Adelman, 1995, p. 22). Hotelling's analysis was not wrong given his assumptions; his assumptions did not hold in the real world. Adelman gave an example concerning the Organization of Petroleum Exporting Counties (OPEC):

> Under competition, low-cost oil would be more quickly and intensively produced in the member countries of OPEC than in non-OPEC countries. . . . [Yet an] anomaly is seen within OPEC. The lower-cost oil is held back; the higher-cost oil is produced. Again it refutes the thesis that higher prices are due to expected still-higher prices acting via "Hotelling rent" (1993, p. xiv).

In his presidential address to the International Association for Energy Economics in 1991, Campbell Watkins declared Hotelling's Rule—called by Robert Solow "the fundamental principle of the economics of exhaustible resources" (quoted in Watkins, 1992, p. 1)—empirically empty.

> The [Hotelling] Principle sees net prices of "exhaustible" resources as following a rising trajectory dictated by the rate of interest. . .. [Yet] the petroleum industry seems to have been unimpressed by this philosopher's stone, supposedly the key to the pricing behavior of the very resource it produces. . .. Empirical evidence for the Principle is largely absent (1992, pp. 1, 22).

An essay published in *The Journal of Economic Literature* in 1998, surveying some 125 articles and books in the 65-year Hotelling-inspired literature, was little kinder. "For the most part," Jeffrey Krautkraemer found, "the implications of this basic Hotelling model have not been consistent with empirical studies of nonrenewable resource prices and *in situ* values" (Krautkraemer, 1998, p. 2066). Hotelling's theory was elegant but misplaced. Real-world phenomena could be explained only by relaxing the assumptions.

## 2.4 "Spaceship Earth": Kenneth Boulding

A fixity/depletionism conception of mineral resources has led some economists to a highly pessimistic, less-is-more recipe for industrial society with activist implications for government policy. In a 1966 address before Resources for the Future, Kenneth Boulding challenged the resource optimism of the day. In "The Economics of the Coming Spaceship Earth," Boulding decried the "reckless, exploitative, romantic,

on me. I have no doubt that if he himself had applied his study of exhaustible resources and looked at the data, he would have come to the right conclusion from it. . . that oil is not as an economic matter an exhaustible resource" (Friedman, 2004).

and violent behavior . . . characteristic of open societies" (Boulding, 1966, p. 9). With exhaustible inputs shrinking, he posited, today's *cowboy economy* would have to transition to a *spaceman economy* where (recycled) inputs and outputs were part of a "cyclical ecological system" (Boulding, 1966, pp. 9, 10).

Boulding's angst over minerals in particular put him at odds with wealth maximization and economic growth. He sought a metric where "lessened throughput is a gain" (Boulding, 1966, p. 9). More was less, for "economic development is the process by which the evil day is brought closer when everything will be gone," Boulding warned. "It will result in final catastrophe unless we treat this interval in the history of man as an opportunity to make the transition to the spaceship earth" (Boulding, 1970, p. 166). He added: "This idea that both production and consumption are bad things rather than good things is very strange to economists, who have been obsessed with the income-flow concepts to the exclusion, almost, of capital-stock concepts" (Boulding, 1970, p. 166).

Writing almost two decades later, Boulding was more cognizant of human ingenuity to forestall resource crises, citing the work of Simon (Boulding, 1985, p. 71). But he remained despairing about the longer term. "There is no doubt that the present 'modern world' of skyscrapers, automobiles, airplanes, electricity, radio and television, and telephones, in its existing technological state rests on the exhaustion of exhaustible resources—oil, gas, coal, ores, minerals, and even soils and forests," he wrote. "It is a very fundamental mathematical principle, that if we are using something up, the time will come when it is all gone" (Boulding, 1985, p. 204). This "entropy problem" brought Boulding back to the "the age old Malthusian [population] problem" (Boulding, 1985, p. 207).

Boulding's pessimism would inspire a new subdiscipline within economics, *ecological economics*, to grapple with resource allocation in a closed system—and government management of the shrinking pie.[6] Ecological economics was an outlier to neoclassical economics, but it, too, can be traced back to the rigid assumptions of Harold Hotelling.

## 3 Austrian views on mineral resources

Economists led by L.C. Gray (U.S. Department of Agriculture), Harold Hotelling (Stanford University; Columbia University), and John Ise (University of Kansas) challenged invisible-hand economics as applied to petroleum and other resources. A.C. Pigou spoke for many others when he said: "It is the clear duty of Government, which is the trustee for unborn generations as well as for its present citizens, to watch over, and if need be, by legislative enactment to defend, the exhaustible natural resources of the country from rash and reckless despoliation" (Pigou, 1932, p. 29).

This popular case for government planning attracted censure from leading Austrian-school economists. Ludwig von Mises, F.A. Hayek, and Murray Rothbard each considered the time distribution of mineral resources in response to the theoretical/political

[6] "The purpose of the [International] Society [for Ecological Economics] shall be the advancement of our understanding of the relationships among ecological, social, and economic systems and the application of this understanding to the mutual well-being of nature and people, especially that of the most vulnerable including future generations." http://www.ecoeco.org/about/const.htm

conservation question. But none developed a thoroughly subjectivist theory of mineral resources. Nor did the Austrians reference Erich Zimmermann, whose work in resource theory offered a subjectivist approach, as described later. Mises, Hayek, and Rothbard accepted and worked within a *fixed-supply framework*, while employing subjectivist economics to refute the notion of market-failure and the need for government planning to ensure resource availability. When it came to minerals, Austrians were as much neoclassical as Austrian.

### 3.1 Ludwig von Mises

In *Nationalökonomie* (von Mises, 1940),[7] which was expanded into *Human Action* (von Mises, 1949), Ludwig von Mises briefly addressed the theory and political economy of mineral resources. Mises starts from the fixity feature of minerals that cannot be synthetically produced in human time frames but only found, as it were. From this basis, Mises goes on to conclude:

1. Exhaustibility is causal for human action in a local sense ("Every single mine or oil source is exhaustible; many of them are already exhausted"[8]). But holistic notions of aggregate supply and future availability are of academic concern and "do not matter for the present-day conduct" of mineral entrepreneurship (von Mises, 1940, p. 581, 1949, p. 637, 1966, p. 641).
2. Acting man faces a variety of mineral-resource opportunities, meaning that choices are made at any one time between developing certain deposits and not other "submarginal" deposits (von Mises, 1940, p. 580, 1949, p. 637, 1966, p. 641).
3. Because of #1 and #2, "the deposits of mineral substances and their exploitation are not characterized by features which would give *a particular mark* to human action dealing with them" (von Mises, 1940, p. 580, 1949, p. 637, 1966, p. 641, emphasis added). Thus, Mises rejects the notion of a special economic rent possessed by resources that he defines as fixed in the aggregate.
4. The "geographical dispersion of natural resources" makes "the problems of transportation . . . a particular factor of production costs" and makes "institutional factors" important (von Mises, 1940, p. 307, 1949, p. 341, 1966, p. 344).

Mises's theory of minerals is thus opposed to that of Harold Hotelling. There is no unique "theory of exhaustible resources" or mineral-resource economics. The history of minerals to Mises points toward enough prospective abundance so that the macroeconomic does not impinge on the microeconomics of human action. The same marginal economic analysis applied, *without* a pronounced reservation demand on the part of the seller to differentiate minerals from other goods and services.[9]

[7] I am indebted to Ebeling and Greaves for their translation help in comparing Nationalökonomie to *Human Action*.

[8] By "exhaustion," Mises meant economic, not physical, exhaustion, along the lines of Jevons who too rejected the notion that "some day our coal seams will be found emptied to the bottom, and swept clean like a coal-cellar" (Jevons 1866, xxix).

[9] The periodic running-out-of-oil scares might have influenced some entrepreneurial decisions at the margin. But overall, the propensity of good entrepreneurship to drive out bad would have limited such Malthusian thinking, which has been exposed time and again as exaggerated (Bradley, in preparation, Chaps. 7–11).

Turning to political economy, Mises observed: “Many people are alarmed by the reckless use of the deposits of minerals and oil which cannot be replaced” (von Mises, 1949, p. 383). Challenging the complaint of market failure from mineral overproduction, Mises stated:

> It is true that the exhaustion of the oil deposits and even those of coal is progressing at a quick rate. But it is very likely that in a hundred or five hundred years people will resort to other methods of producing heat and power. Nobody knows whether we, in being less profligate with these deposits, would not deprive ourselves without any advantage to men of the twenty-first or of the twenty-fourth centuries. It is vain to provide for the needs of ages the technical abilities of which we cannot even dream (von Mises, 1949, p. 383).

Indeed, as Smil notes, referring to research done by Cesare Marchetti, there have been “orderly transitions” (Smil, 2000, p. 257) between primary energies in world history, the most important of which was a shift from wood to coal in the sixteenth-century (Bradley and Fulmer, 2004, p. 91). And government bets on synthetic fuels after World War II and during the 1970s fell well short of expectations (Bradley, 1996, p. 569). Still, Mises was not oblivious to a faulty allocation of production between time periods. But, unlike the conservationists, he linked overexploitation (a negative externality) with an absence of private property rights:

> It is true that where a considerable part of the costs incurred are external costs from the point of view of the acting individuals or firms, the economic calculation established by them is manifestly defective and their results deceptive. But this is not the outcome of alleged deficiencies inherent in the system of private ownership of the means of production. It is on the contrary a consequence of loopholes left in this system. It could be removed by a reform of the laws concerning liability of damages inflicted and by rescinding the institutional barriers preventing the full operation of private ownership (von Mises, 1949, p. 653).

Mises left the earlier-mentioned paragraphs unchanged in his last revised edition of *Human Action* (von Mises, 1966, pp. 386, 657) and would not otherwise address the theory or political economy of mineral resources.

### 3.2 F. A. Hayek

In *The Pure Theory of Capital*, Hayek contrasted “wasting natural resources” (Hayek, 1941, p. 88) with the produced means of production. Both were considered capital, but only the latter were considered *capital goods,* a new and useful output created by the land-labor-capital triad (Hayek, 1941, p. 91).

Hayek was wed to Hotelling-like fixity/depletionism when he stated that “mineral resources are inevitably exhausted by their use and cannot possibly render the same services forever” (Hayek, 1941, p. 51). But “forever” is outside of economic time, which ranges from the moment to years, decades, and even centuries when talking about a particular mineral form. To his credit, Hayek understood that a mineral-resource firm had to continually find more (exhaustible) supply to remain a going concern. But he was in the Hotelling-world when he concluded: “If income is to be maintained permanently at the higher level which the wasting natural resources make possible, these resources will, as they are exhausted, have to be replaced by produced means of production" (Hayek, 1941, p. 88).[10]

Hayek's jump to a long-run, objective, macro equilibrium obviates real-world disequilibrium where firms continually (and open-endedly) replace minerals with minerals, as the crude oil industry has done for 150 years, and other mineral industries have done for far longer. Highly specialized and expert firms in these industries, seeking and receiving competitive returns, maintain and expand their capital by tapping into an unknown and to them unknowable universe of supply.

Hayek's interest in markets versus central planning brought him face-to-face with economists embracing government direction of mineral development. A chapter in *The Constitution of Liberty* (Hayek, 1960) focused on the political economy of mineral-resource development.[11]

Hayek, like Mises, noted the "prevalent opinion" that market decision-makers were overproducing "irreplaceable resources" (Hayek, 1960, pp. 367, 369). "Few arguments have been used so widely and effectively to persuade the public of the 'wastefulness of competition' and the desirability of a central direction of important economic activities as the alleged squandering of natural resources by private enterprise" (Hayek, 1960, p. 367).

Hayek employed familiar reasoning to explain how privately owned resources had a capital or salable value, which was particularly relevant to mineral deposits for which, *ceteris paribus*, present production meant less future production.[12] In his words:

> If the owner can get a higher return by selling to those who want to conserve than by exploiting the particular resource himself, he will do so. There will normally exist a potential sale price of the resource which will reflect opinion about all the factors likely to affect its future value, and a decision based on the comparison of its value as a salable asset with what it would bring if exploited now will probably take into account more of all the relevant knowledge than could any decision of a central authority (Hayek, 1960, p. 372).

Hayek complemented his market rationality argument with an open-ended view of resources wherein one resource gives way to another—a stock-to-flow analysis that Mises had emphasized as well. Stated Hayek:

[10] Hayek's holism becomes economy-wide when he adds that "any exhaustible resource represents just one item of the national capital which may be more useful in some other form into which it can be converted" (Hayek, 1960, p. 88).

[11] Machlup (1952, p. 299), an Austrian-trained economist, presented a standard neoclassical treatment of what he called organic (renewable) and inorganic (nonrenewable) resources. Unlike Hayek, Mises, and Rothbard, however, he saw market failure in the case of petroleum and advocated a role for government. Machlup did recognize the deterioration of government conservation policy into a politicized price-maintenance program benefiting producers.

[12] Hayek did not dirty his hands with the economists' favorite case study of resource overexploitation: oil production under the rule-of-capture. This situation arose where drainage competition occurred between coowners of a reservoir containing a fungible mineral, driving up costs and even damaging recoverability. (This race for possession was not present with hard minerals since surface boundaries protected asset deposits.) An Austrian-institutional reinterpretation of the "common pool" problem of oil production under the rule of capture has been set forth by this author (Bradley, 1996, Chaps. 2–4).

> Any natural resource represents just one item of our total endowment of exhaustible resources, and our problem is not to preserve this stock in any particular form, but always to maintain it in a form that will make the most desirable contribution to total income. The existence of a particular natural resource merely means that, while it lasts, its temporary contribution to our income will help us to create new ones which will similarly assist us in the future (Hayek, 1960, p. 374).

Exploiting (depleting) fixed resources promotes future progress because wealth is created from present usage, and higher prices signal the market to develop substitutes. Hayek explained: "We are constantly using up resources on the basis of the mere probability that our knowledge of available resources will increase indefinitely—and this knowledge does increase in part because we are using up what is available at such a fast rate" (Hayek, 1960, p. 369).

Hayek was dubious about a government solution to an overproduction problem, elaborating on the argument that Mises made more than a decade before:

> The claim that the government possesses superior knowledge raises a more complex problem. . . . There will always exist . . . an even greater store of knowledge of special circumstances that ought to be taken into account in decisions about specific resources which only the individual owners will possess and which can never be concentrated within a single authority. Thus, if it is true that the government is likely to know some facts known to few others, it is equally true that the government will be necessarily ignorant of an even greater number of relevant facts known to some others (Hayek, 1960, p. 371).

Hayek posited the knowledge problem in the particular context of exhaustible resources:

> The problem concern[ing] the rate at which stock resources, such as mineral deposits ought to be used up . . . presupposes a rational estimate of the future course of prices of the materials in question, and this in turn depends on forecasts of future technological and economic developments which the small individual owner is usually not in a position to make intelligently (Hayek, 1960, p. 371).

Yet government does not possess such knowledge to define and correct the alleged problem. "Most of those who complain about what has happened, however, are being wise after the event," stated Hayek, "and there is little reason to believe that, with the knowledge available at the time, even the most intelligent governmental policy could have prevented those effects which are now most deplored" (Hayek, 1960, p. 368). Enforced conservation in ages past, in fact, would have held back the progress responsible for today's high standards of living and the capacity to mine new resources.

> Industrial development would have been greatly retarded if sixty or eighty years ago the warning of the conservationists about the threatening exhaustion of the supply of coal had been heeded; and the internal combustion engine would never have revolutionized transport if its use had been limited to the then known supplies of oil (during the first few decades of the era of the automobile and the airplane the known resources of oil at the current rate of use would have been exhausted in ten years). Though it is important that on all these matters

> the opinion of the experts about the physical facts should be heard, the result in most instances would have been very detrimental if they had had the power to enforce their views on policy (Hayek, 1960, p. 369).

Hayek then exposed the circularity of the argument being put forward by those urging postponed use for its own sake:

> All resource conservation constitutes investment and should be judged by precisely the same criteria as all other investment. . .. To extend investment in the conservation of a particular natural resource to a point where the return is lower than the capital it uses would bring elsewhere would reduce future income below what it would otherwise be. As has been well said, "the conservationist who urges us 'to make greater provision for the future'" is in fact urging a lesser provision for posterity (Hayek, 1960, p. 374).

Market failure as a rationale for government intervention was effectively rebutted.

## 3.3 Murray Rothbard

Rothbard repeatedly addressed the economics and political economy of resource conservation. "The market will tend to use resources at precisely the rate the consumers desire," Rothbard concluded (Rothbard, 1962, p. 500). Market coordination, not market failure, was encouraged by price signals, time preference, capital values, and entrepreneurial speculation within a private property, voluntary-exchange framework (Rothbard, 1962, p. 498, 1970, p. 1125).

Rothbard censured government-imposed conservation as flawed in theory (Rothbard, 1962, p. 496, 1973, p. 247) and practice (Rothbard, 1970, p. 1126, 1973, p. 249). Conservation laws postponing production, and thus consumption, were "grants of monopolistic privilege" (Rothbard, 1970, p. 1129). An *absence* of private property rights was behind "several particular natural resources [that] have suffered, in the past and now, from depletion" (Rothbard, 1973, p. 250). Such a "'war of all against all'" was a failure of government to assign and protect property rights, not capitalism per se (Rothbard, 1970, p. 1127).

But Rothbard held a static, objectivist theory of mineral resources premised on fixity and depletion, which he defined as "a special division under the 'land' category."

> There is one type of resource that is nonreplaceable but also nonpermanent: the natural resource that is being depleted, such as a copper or a diamond mine. Here the factor is definitely original and nature-given; it cannot be produced by man. On the other hand, it is not permanent, but subject to depletion *because any use of it leaves an absolutely smaller amount for use in the future* (Rothbard, 1962, p. 496, emphasis added).

Confusing natural-science nonreproducibility with the praxeological concept of entrepreneurial discovery (or what this paper calls *resourceship*), Rothbard concluded that "resources subject to depletion cannot be replaced, much as the owner would like to do so" (Rothbard, 1962, p. 497).

Without explicitly invoking a Hotelling notion of premium pricing of minerals, Rothbard hinted at a special economic rent. "There can be a reserve demand for a depletable resource, just as there is speculative reserve demand for any other stock of goods on the market," he stated (Rothbard, 1962, p. 498). "The key question is whether a resource has to be produced, in which case it earns only *gross* rents. If it does not or cannot, it earns *net* rents as well" (Rothbard, 1962, p. 484).

Still, Rothbard sought to break out of the equilibrium, objectivist box. In his final treatment of the subject, he spoke of "growing technology" that "not only uses up, but also adds to, usable natural resources" (Rothbard, 1974, p. 181). He explained:

> Before the development of the automobile and of modern machinery, the vast pools of petroleum under the earth were totally valueless to man; they were useless, black liquid. With the development of modern technology and industry, they suddenly became useful resources (Rothbard, 1974, p. 181).

Rothbard's demand-push view on resource creation was not joined by a supply-side emphasis on resource *creation*, or resourceship, where *economic* resources are created out of site-specific, in-place matter. Rothbard had elsewhere spoken of turning *geographic* land into *economic* land (Rothbard, 1962, pp. 169, 485), but he did not see the parallelism in turning matter into mineral resources.

Rothbard noted that "raw material and natural resource prices have remained low, and have generally declined relative to other prices." Credit was given to "cheap substitutes."[13] He continued toward a supply-side theory by noting how "modern technology, through improved geological techniques and through the incentive of the market, has been finding new petroleum reserves at a rapid rate" (Rothbard, 1973, p. 249). Still, a thoroughgoing subjectivist theory of mineral resources was absent.

### 3.4 Austrians and neoclassicism

Mises had a more "Austrian" view of minerals than Hayek and Rothbard, explicitly demoting the fact of aggregate mineral fixity as a causal factor in economic decision-making. Still, Mises implied that minerals are (1) fixed in the aggregate in a social-science sense and (2) found rather than created by entrepreneurship. To Mises, entrepreneurs do not produce resources, they "exploit" them, and mines are less created than "utilized" (von Mises, 1949, p. 641). This passivity toward the entrepreneurial mineral-resource function also appears in Mises's aforementioned view on the political economy of mineral-resource conservation.

Hayek and Rothbard more explicitly adopted a neoclassical framework. They described minerals as nonrenewable, as did Mises. But they went further by viewing depletion as significant not only for the individual deposit but for *a known or knowable fixed aggregate supply*. Hayek and Rothbard implied that extraction reduces the universe of supply—and both cited Anthony Scott's *Natural Resources* (Scott, 1955), a work in the Jevons–Gray–Hotelling tradition. Scott held a static view of mineral resource development, citing the "well-known fact" that mining goes from high-grade to low-grade stocks, forcing society "to incur higher costs in using them" (Scott, 1955, p. 13). Scott criticized conservation-for-its-own-sake and government resource

[13] Mineral-for-mineral substitution in the neoclassical (and Rothbardian) framework would still be within two fixed supplies. However, to the extent that a mineral can be effectively recycled (e.g., copper), supply is more elastic to price, and depletion scarcity can be postponed.

planning—criticisms made by the Austrians before and after him. But unlike the Austrians, Scott blessed government intervention to "prevent activities which produce a net social loss" (Scott, 1955, p. 66) given the "social diseconomies of depletion" (Scott, 1955, p. 53).

Seen another way, this Austrian view of minerals is akin to the allocative, economizing brand of economic science, which sees the economy as allocating scarce means to alternative ends—as if means and ends were *given*. As argued in Section 5, the Austrian approach views economic action more broadly.

## 4 The functional theory of resources

Erich Zimmermann (1888–1961) penned the first treatise on mineral-resource economics since Jevons's *The Coal Question* more than a half century before. *World Resources and Industries* (1933a, revised 1951), presented a new way of viewing minerals and found an audience within the extractive industries and among some economists. Zimmermann's alternative *gestalt*, however, did not penetrate the economics mainstream of neoclassical formalism. Neither did his self-described *functional theory* find a champion within Austrian-school economics. If it had, Mises's view of minerals might have been even more open-ended, and Hayek and Rothbard might have questioned aggregate fixity as an operative social-science concept.

Zimmermann (1951, p. 6) identified resource theory as the "stepchild" of economic analysis. "If [resources] were recognized at all, they were absorbed into the market process, acknowledged only in so far as they were reduced to working tools of the entrepreneur—land, labor, and capital—or recognized through their effects on cost and price, supply, and demand" (Zimmermann, 1951). What was needed was a theory of "human and cultural resources" (Zimmermann, 1951), for

> Nature and culture have become so intertwined that little can be gained from an attempt to isolate the natural resources. Cultural and natural resources are inseparable and can only be considered together (Zimmermann, 1933b, p. 215).

He described his contribution as the *functional* theory of resources since "the concept of resources is purely functional, inseparable from human wants and human capabilities" (Zimmermann, 1945, p. 159).

### 4.1 Subjectivism/methodological individualism

Causality in Zimmermann's functional theory comes from the mind of the economic decision-maker. Resources, defined as "the environment in the service of man," are "an expression of appraisal and, hence, a purely subjective concept" (Zimmermann, 1933a, p. 3). Thus, "*a man-less universe is void of resources*; for resources are inseparable from man and his wants" (Zimmermann, 1933a, p. 3). Zimmermann explained:

> Previous to the emergence of man, the earth was replete with fertile soil, with trees and edible fruits, with rivers and waterfalls, with coal beds, oil pools, and mineral deposits; the forces of gravitation, of electro-magnetism, of radio-activity were there; the sun sent forth his life-bringing rays, gathered

> the clouds, raised the winds; but there were no resources (Zimmermann, 1933a, p. 3).

Zimmermann-qua-social-scientist demoted the natural-science conception of resources. “The word ‘resource’ *does not refer to a thing or a substance but to a function which a thing or a substance may perform or to an operation in which it may take part*, namely, the function or operation of attaining a given end such as satisfying a want.” He elaborated:

> Resources are means to ends. Means derive their meaning from the ends which they serve. Ends suggest purpose. Purpose springs from the human mind, from the mind of individuals or of groups of individuals. Resources, therefore, reflect the subjective appraisal of those who purposefully choose means to accomplish given ends (Zimmermann, 1945, p. 157).

He differentiated clearly between two arenas of scientific knowledge. “To the physicist the law of the conservation of matter and energy is basic,” Zimmermann noted; “the economist, however, is less interested in the totality of the supply than in its availability” (Zimmermann, 1933a, p. 45).

Zimmermann knew that he was forging new ground and challenging methodological fashion in the social sciences. “To those who are used to view resources as material fixtures of physical nature, this functional interpretation of resources must seem disconcerting,” he said, because “it robs the resource concept of its concreteness and turns it into an elusive vapor” (Zimmermann, 1933a, p. 4). Zimmermann faced the same uphill fight as Austrian school economists did across the spectrum of theoretical economics, from monetary theory to capital theory to competition theory, and more. Methodological subjectivism was out; objectivism—mathematical model-building and measurement and statistical testing of falsifiable propositions—was in. Turning physical nonreproducibility into economic fixity, and calculating depletion from fixity, was the North Star of economists who saw quantitative relationships as the sine qua non of science.

Zimmermann was a methodological individualist. Causality came from the parts, not from a calculated or imagined whole. Zimmermann warned against the “unfortunate ... tendency to think of resources in terms of a single asset, e.g., coal, rather than the whole complex of substances, forces, conditions, relationships, institutions, policies, etc., which alone help to explain the way coal functions as a resource at a given time and place” (Zimmermann, 1951, p. 7).

### 4.2 Dynamics/institutionalism

Resources to Zimmermann were conditional things that are created and destroyed by changes in consumer demand. “Resources are dynamic not only in response to increased knowledge, improved arts, expanding science,” he wrote, “but also in response to changing individual wants and social objectives” (Zimmermann, 1951, p. 11). This was not *a priori* theory but empirical fact. “One has but to recall some of the most precious resources of our age—electricity, oil, nuclear energy—to see who is right, the exponent of the static school who insists that ‘resources are,’ or the defender of the dynamic, functional, operational school who insists that 'resources become'" (Zimmermann, 1951, p. 7).

Different resources were more than mere variety; they were potential substitutes. That was good news, given the cumulative nature of scientific discovery, which entails that "each invention gives rise to numerous others" (Zimmermann, 1951, p. 73). This interpretation of *expanding*, *cascading* invention, would be seized upon by later thinkers to bring the functional theory of resources to its grand conclusion—recognition of the vast potential of the earth to overcome, even overwhelm, the finiteness of Thomas Malthus and the diminishing returns of David Ricardo.

Zimmermann's functional theory was aligned with Joseph Schumpeter's theory of *creative destruction* (Schumpeter, 1942, p. 83). Zimmermann wrote:

> Yet while changed or expanding wants create new resources, others are destroyed. Progress always means a net gain but seldom a pure gain. Creating the better, we must often destroy the good (Zimmermann, 1951, p. 17).

Greatly influenced by the performance and heterogeneity of institutions, Zimmermann viewed resources as highly elastic. Resources could be created, but they could also be immobilized by acts of man. In his words:

> The resources at the disposal of man evolve out of the working combination of natural, human, and cultural aspects—a combination which expands with every advance of human knowledge and wisdom and contracts with every relapse into the barbarism of war and civil strife (Zimmermann, 1945, p. 160).

Zimmermann elaborated:

> A functional interpretation of resources . . . makes any static interpretation of a region's resources appear futile; for resources change not only with every change of social objectives, respond to every revision of the standard of living, change with each new alignment of classes and individuals, but also with every change in the state of the arts—institutional as well as technological (Zimmermann, 1933b, p. 216).

And again: "Laws, political attitudes, and government policies, along with basic geological and geographical facts, become the strategic factors in determining which oil fields will be converted by foreign capital from useless 'neutral stuff' into the most coveted resource of modern times" (Zimmermann, 1951, p. 16).

The institutionalists' emphasis on technological change predated Zimmermann, going back to at least Veblen (1906, p. 15). Zimmermann polished his functional theory with the help of Wesley Mitchell, who opined:

> Incomparably greatest among human resources is knowledge. It is the greatest because it is the mother of other resources (Mitchell, 1941, p. 1, quoted in Zimmermann, 1951, p. 9).

Still, Zimmermann put together the pieces in a highly original and compelling way. The profundity of his functional theory of resources is a major underappreciated contribution to economic thought.

### 4.3 Knowledge: The ultimate resource

Julian Simon is closely associated with the concept of human ingenuity as the *ultimate resource* (Simon, 1981, p. 348). Institutional economists grasped this concept decades earlier, however, starting at least with Wesley Mitchell (1941, p. 1). Zimmermann cited and restated Mitchell's point several times prior to Simon's formulation:

- "Freedom and wisdom, the fruits of knowledge, are the fountainhead of resources" (Zimmermann, 1945, p. 159);
- "Man's own wisdom is his premier resource—the key resource that unlocks the universe" (Zimmermann, 1951, p. 7);
- "The bulk of MAN's resources are the result of human ingenuity, aided by slowly, patiently, painfully acquired knowledge and experience" (Zimmermann, 1951, p. 9).

Still, there was much empirical work to buttress a theory of open-ended development, and Julian Simon, following the early studies sponsored by Resources for the Future, did much to unlock the statistical record to show that the prices of mineral and natural resources did not behave (or at least had not behaved) differently from those of reproducible goods. He particularly dwelt on petroleum, "the most counter-intuitive case of all" (Simon, 1995, p. 11). Simon, like M. A. Adelman, concluded: "Malthusian diminishing returns theory does not fit these observed facts and is not compelling intellectually; a theory of endogenous invention is more persuasive in my view" (Simon, 1990, p. 432). Yet Simon spent precious little time on this theory. Erich Zimmermann did and provided a theoretical framework that Simon encountered but scarcely acknowledged.[14]

### 4.4 Falling short: The fixity/depletionism conundrum

Zimmermann's subjectivist theory of resourceship allowed him to *almost* escape from the fixity/depletionism straitjacket of mineral-resource economics. Zimmermann's vision of the concept of a "resource" was expansive enough for him to realize that a wholly new resource could perform the same services as a preexisting resource. He expressed his open-ended view of minerals in memorable language:

> Resources are not, they become; they evolve out of the triune interaction of nature, man, and culture, in which nature sets outer limits, but man and culture are largely responsible for the portion of physical totality that is made available for human use. . . . The problem of resource adequacy for the ages to come will involve wisdom more than limits set by nature (Zimmermann, 1951, p. 35).

Yet *despite* teeing-up a theory with rich implications for expanding supply and interresource substitution; *despite* identifying the human mind as the engine of resource creation, *despite* presenting an array of price and quantity statistics showing how oil, gas, and coal were growing; and *despite* declaring the vision of Malthus

[14] In his editions of *The Ultimate Resource* (Simon, 1981, p. 403, 1996, p. 690), Simon lists *World Resources and Industries* in the bibliography but misspells the author name as Zimmerman (instead of Zimmermann).

"obsolete," (Zimmermann, 1933a, p. 813). Zimmermann had a pessimistic streak, even suggesting that he was a depletionist at heart. His particular concern was the rapid production of oil and gas in the United States, but his angst extended to hard minerals as well. To Zimmermann, the statistics of plenty were not the systemic triumph of human ingenuity and the evidence of an open-ended resource future; they were a sign of *overproduction*, of "warped appraisal" in favor of present output (Zimmermann, 1933a, p. 23). He complained: "Often private profits are made at the expense of appalling long-run social waste" (1957, p. 126). This "tempo problem" for Zimmermann was a *market failure* and a concern of government, which "as the political embodiment of the group ... takes in the conservation of the limited non-renewable resources" (Zimmermann, 1933a, p. 19).

Zimmermann differentiated between a "transient" civilization based on exhaustible resources and a permanent one based on renewables (Zimmermann, 1933a, p. 71)—as if resources *were* and *could no longer become*. The Jevons–Gray–Hotelling view of mineral resources, banished through the front door, re-entered though the back. Zimmermann, ironically, feared the very thing that his functional theory demoted—fixity/depletionism.

Zimmermann could have brought his functional theory to an optimistic conclusion: that constraints toward *particular* resources are overcome by the propensity of human capital to expand the *family* of resources.[15] Yet, even while denying the importance of fixity through the idea that "resources become," Zimmermann continued to focus on minerals as synthetically nonreproducible. His statement "resources are not, they become" really said "*fixed* resources are not, they become." And that meant resources do not become. As with Hayek and Rothbard, and to a lesser extent Mises, still another step was necessary for Zimmermann to complete the escape from the neoclassical formalism of Jevons, Gray, and Hotelling.

## 5 An Austrian theory of mineral resources

Zimmermann's functional theory presented an on-the-shelf subjectivist theory that leading Austrians surely would have assimilated had they known about it. Zimmermann's "resources" in place of "neutral stuff" was akin to Menger's differentiation between *goods* and *things* (Menger, 1871, p. 52). Zimmermann's *individualistic*, *subjectivist*, *functional*, *dynamic* theory stood in bold relief to the *aggregative*, *objective*, *overly theoretical*, *static* approach of neoclassicism. Little wonder that Zimmermann dismissed Harold Hotelling's approach as "a jumble of numbers" (quoted by McDonald, 2003).[16]

Yet Zimmermann, like the Austrians, accepted the view that the physical nonreproducibility of minerals had driving economic significance for resources. To turn the noun "resources" into the verb "resourcing"—to discard the very idea of a resource "glass" being somewhere between full and empty—requires another step in the

[15] Unlike Zimmermann, other institutionalists have emphasized the expanding nature of aggregate resources over time (DeGregori, 1985, Chap. 5).

[16] Similarly, Mises described mathematical economics as "sterile" and worse still, "divert[ing] the mind from the study of real problems and ... the relationships between the various phenomena" (von Mises, 1966, p. 350).

analysis. Because we cannot know the total quantity of any mineral, we cannot say what percentage has been used or at what rate (in percentage terms) it is being used. Nor can we specify how much remains potentially available or at what rate it might be available, for those things depend on future technology, which is also unknowable.

For economics, the absence of any knowable physical or technological limits on our potential to produce a given mineral produces a situation functionally equivalent to a situation in which synthetic additions could be made to that mineral supply. Restated, today's *supply* of a "fixed" mineral is just as *re*producible as it would be if we could synthetically create the substance. *Resourceship*, the positive act of mineral creation, is thus *praxeologically* akin to manufacturing in a factory.

But questions of geography and institutions are even more important for mineral economics than they are for nonmineral economics given the nature of physical supply.[17]

## 5.1 Open-endedness

The confounding of physics with economics has plagued a real-world understanding of mineral resources. The phenomenon of entropy and the laws of thermodynamics rule in their domain. But *there is no economic law analogous to the physical conservation of matter*. There is no law of conservation of value; value is continually, routinely created by the market process. And this value creation does not deplete.

Israel Kirzner in the Austrian-School tradition has emphasized the open-endedness of market entrepreneurship. "Entrepreneurial alertness [is] in principle inexhaustible," Kirzner has stated (Kirzner, 1980, p. 25), wholly rejecting the notion of a "*potential* stock of entrepreneurial alertness in a society as some quantity 'available to be used by society'" (Kirzher, 1980, p. 23). In the vernacular of the oil industry, there are no reservoirs of proved, probable, or speculative quantities for entrepreneurship.

The institutionalist conception of knowledge as the ultimate resource powerfully complements an Austrian theory of resources. DeGregori has defined resources as "a set of capabilities" (DeGregori, 1987, p. 1243) and "finite but unbounded" (DeGregori, 1987, p. 1259). He restated and embellished the Zimmermann thesis as follows:

> Technology as ideas and as the creator of resources is not only correct, it is also liberating. It provides a conceptual basis for understanding the fact that the resource base of civilization has expanded, not contracted, with use. It gives us the kind of operational understanding necessary to frame the policies to sustain this resource-creating process. It provides a reasonable basis for optimism that the human endeavor can continue and can expand. It is, finally, the key component of a structure that challenges traditional ways of thought about the economy and opens new possibilities for creative inquiry and dialogue (DeGregori, 1987, p. 1258).

By the same token, however, "We will exhaust resources if we exhaust creative imagination" (DeGregori, 1987, p. 1260).

[17] However, minerals can be transformed above ground such as natural gas being liquefied into motor gasoline. Gas-to-liquids technology in this case transforms a lower-valued product into a higher-valued one.

The open-endedness of entrepreneurship is an implication of the fact that "there is no law of decreasing returns to technological progress" (Schumpeter, 1954, p. 263). New knowledge and discovery open up the opportunities for *more* and *greater* discoveries from a rich, noninventoried earth. The central role of knowledge as the ultimate resource and creator of minerals is—or should be—a fundamental principle of economics" (DeGregori, 1987, p. 1243). Still, the resource of the human mind is only potential unless ingenuity turns into result. The central role of institutions in the capitalist discovery process is considered in Section 5.6 later.

Land, not only minerals, is an open-ended resource. Land in the economic process is not fixed but fashioned from the neutral stuff of the earth. Irrigation, fertilizing, planting, and tilling turn a physical good into an economic one. There is also level-surface *creation* where human action creates surface space below or above the original ground level. Land augmentation can also come from surfacing water areas with temporary or permanent structures. The natural scientist can estimate the total area of the Earth's raw (ground-level) surface. But this is a bare minimum given the ability of science and technology to create ("manufacture") land, as it can minerals. "Land as a human resource is created by technology and science in the same manner as minerals become resources" (DeGregori, 1987, p. 1254).

The total supply of any mineral is unknown and unknowable because the future knowledge that would create mineral resources cannot be known before its time. (Popper 1957, p. vi–vii). Estimates can and have been made as to the raw physical (in-place) supply. A subset of this quantity is economical supply. "What we observe in the real world are not one-time stocks immaculately created to be consumed," Adelman stated, "but inventories of 'proved reserves,' constantly renewed by investment in finding and development" (Adelman, 1991a, p. 241).

Substitutability is part, but only part, of open-endedness. Minerals have sister resources that can perform the same or a similar function, although often at a higher cost, at least for the transition period. Tar sands in the Canadian province of Alberta can be manufactured to produce a substitute for crude oil for petroleum refining. Gasified coal can substitute for natural gas. Natural gas can be manufactured into liquids, even motor gasoline. Recycling can create resources where none were before. Human ingenuity and capital investment under a regime of economic calculation can lead society to new combinations of minerals—or minerals and nonminerals—to perform the same (or better) economic services over time. The process can even morph between goods that are considered depletable (in the natural science sense) and ones that are considered nondepletable, for example, between crude oil and agricultural oils (ethanol, biodiesel).

## 5.2 Producibility-as-reproducibility

Outside of Hotelling-inspired neoclassical theory, minerals do not exist in known, finished form; the supply is not taken off the shelf. Minerals are not simply collected, gathered, or mined—or extracted, separated, or exploited—in the sense of obtaining ready-made supply. Minerals are created, produced, augmented—*manufactured* as it were, from the chaos of matter—with the use of highly complex, capital-intensive processes that turn physical matter into economic goods. The *Oxford English Dictionary* defines the act of manufacturing as, "To make or fabricate from material;

to produce by labor (now especially on a large scale)" (Oxford English Dictionary, 1933, s.v., "manufacture"). This definition can be applied to minerals, whose supply is proactively created, not reactively found.

Resourceship uses land, labor, and capital to create economic goods. The fact that minerals cannot be naturally or artificially created in significant quantities (within a human time-frame)—giving rise to the natural-science concept of mineral fixity—is secondary. Technological producibility, not physical creatability, matters for praxeology.

The producibility (and thus creatability) of the supply of oil and other minerals encompasses exploring in new "frontier" areas (wildcat drilling), drilling in known, developed areas (infill or development drilling), or rehabilitating existing properties (e.g., repressuring a reservoir). A mineral entrepreneur can augment supply by buying properties from another operator, probably with the idea of increasing output per unit of input (increasing economic supply). Throughout these processes, an operator might introduce new technologies to transform potential into actual resources. From all this, "there is no fixed mineral stock, only an uncertain flow into mineral inventories, 'proved reserves'" (Adelman, 1991a,b, p. 262).

### 5.3 Whither "depletable/nondepletable"

Mainstream economists have increasingly noted the nonoperational nature of Hotelling's Rule. A few have even questioned the very distinction between renewable and nonrenewable commodities. Adelman has stated:

> The economic theory of mineral deposits has been that of a non-renewable inventory . . . used at such a rate over time as to maximize its present value. This theory is logically sound, but it appears less useful the more we learn the nature of the inventory. The distinction between renewable and non-renewable resources is tenuous and perhaps in the last analysis untenable (Adelman 1970, p. 66).

"'Finite limited resources'. . .is an empty slogan," Adelman has concluded. "Only cost and price matter" (Adelman, 1991b, p. 538).[18] Friedman was hot on the same trail when he noted that oil, gas, and coal are "producible . . . at more or less constant or indeed declining cost because of the improvements in the technology of drilling and exploring and so on" (Friedman, 1978, p. 12).

The renewable/nonrenewable distinction is a misleading categorization when applied to economics and public policy. The notion of absolute fixity/depletionism has lead to sterile modeling, superficial acceptance of market-failure, and calls for government-engineered conservation (conservationism). The sciences of human action need to undertake a fundamental reconsideration of this natural-science distinction.

[18] Adelman adds: "We cannot rescue the concept of a fixed mineral stock by making it 'the economic portion' of the unknown total in the ground. That is circular reasoning. For the 'economic portion' depends on future costs and prices. One cannot estimate future costs and prices by starting with their result. The 'economic portion' is a forecast, an implicit unverifiable prediction of how much inventory will be worth creating and using" (Adelman, 1993, p. 271).

The very term "natural resource" in the sense of a special category of economics has been challenged as a misnomer. "Resources are not fixed and finite because they are not natural," Zimmermann student and disciple DeGregori stated. "They are a product of human ingenuity resulting from the creation of technology and science" (DeGregori, 1987, p. 1247). Furthermore, the "economics of exhaustible resources" does not so much apply to minerals proper as to *any good or service* perceived by the decision-maker to be fixed in supply. Depletion from a fixed stock (as calculated by a decision-maker, in terms of his particular circumstances) can apply to a canteen of water in the desert (a good) or the productive years of a professional football player (a service). In such cases, there can be a heightened reservation demand (withholding supply from the market), adding uniqueness to a situation where a well-defined supply is not augmentable.[19]

The causal factor is whether or not human action views a supply as fixed, and thus production/consumption as drawing on a strictly limited, nonaugmentable, supply. "Stock economics" is a concept very different from "mineral economics"; the latter may or may not provide examples for the former.

## 5.4 Capital intensity

The word "metal" comes from the Greek *metallan*, which means to seek after, or to explore. Mineral supply was once the work of labor using simple tools, a gathering function. But the mineral-resource industries are now as complex and multistage as any in the world. The extractive industries will become ever more capital intensive as more supply is demanded, and thus more must be found, with a propensity to mine deeper and mine less pure grades. It is theoretically possible, however, for a substitute to be found that is less capital intensive than the mineral whose services it replaces. The vital role of capitalism's capital—the savings and investment generated by a market economy—to locate and produce new deposits at stable or declining cost is oft-overlooked in current debates over mineral resource policy.

A structure of production can be mapped for all economic goods. The consumer, retail stage would be at the base, with wholesaling just above. At the other end of the diagram would be the most remote processes from the consumer, such as the mined iron ore that goes into the machinery used in the production of the drill bit that penetrates the oil reservoir. When one thinks of offshore drilling where platforms are constructed for the surface and robots are assembled for operations on the ocean floor, the structure of production becomes one of almost unimaginable complexity.

Energy has been called the *master resource* because it enables the conversion of one material into another (Simon, 1996, p. 162) and because it is ubiquitous to economic activity. Energy, in fact, can almost be thought of as the *fourth* factor of production in addition to land, labor, and capital. Its capital structure, and the investment behind it, is one of the marvels of the modern world that has grown up around capitalism.

[19] As an example of elevated reservation demand, in 1991 some major natural gas producers shut-in their flowing supply as an alternative to drilling for more gas, in effect saving drilling costs and producing at a later date when gas prices were anticipated to be higher (Weak Demand, 1991, p. 27).

## 5.5 The centrality of geography (location)

Rejecting the fixed, known conception of resources, and thus the importance of the renewable–nonrenewable distinction, leaves the question: *what is the difference between minerals and nonminerals for the sciences of human action*? The answer was grasped by J.E. Cairnes who wrote in the nineteenth century:

> The sources from which [minerals] are obtained are distributed over the earth with very great inequality; some countries being entirely destitute of them; others possessing them in great abundance, and of the most varied degrees of fertility; and secondly, their production is more mechanical in its nature than that of agriculture or pastoral products, from which it results that their cost of production is more directly dependent, than that of other rude products, on the progress of mechanical and chemical invention (Cairnes, 1874, p. 131).

Fixed, known supply is not mentioned as a characteristic of minerals in Cairnes's brief treatment of the subject, and he does not posit a tendency toward depletion, creating higher costs and higher selling prices. He noted how the "great variation of the normal prices of mineral products" (Cairnes, 1874, p. 132) could go in either direction. Future prices depended on future discoveries of deposits, which, in turn, depended on scientific improvement over time (Cairnes, 1874).

Frank Knight also noted the importance of geography and regional specialization with minerals that "can only be extracted where they exist" (Knight, 1933, p. 19). He added, "The question of political interference with territorial specialization, through 'tariffs', bounties, subsidies and the like, has formed an important political issue in all modern nations" (Knight, 1933, p. 20).

Geographical considerations are oft-cited in discussions of mineral scarcity. "It is our view that very few important materials in the world—perhaps none—will become unduly scarce," stated Alfred E. Kahn et al., "although the distribution of the prime sources of many of them is so uneven that unless we are careful cartels might occasionally be able to extract higher prices than usual from consumers, thus causing local needs for conservation, substitution, and redesign" (Kahn et al., 1977, p. 87). Empirical evidence of this point can be found with OPEC and other mineral cartels, which for a time, at least, have been able to use the power of government to keep prices well above finding costs (Adelman, 1995, p. 329).

## 5.6 Institutions

An Austrian theory of mineral resources points toward a new research program. Instead of eyeing scarcity through the prism of estimated found or remaining supply, research would center on the institutional arrangements, beginning with property rights and ending with the incentive and ability to perform economic calculation, that encourage (or discourage) the exploration and production of minerals. Minerals in different geographical areas will be found to be overexploited or underexploited at any one time owing to different laws and customs. Scarcity values (prices) will be found to be artificially low or high at any one time given this heterogeneity. For example, the extreme volatility of prices for crude oil, a global commodity, can hardly be explained by Hotelling's Rule. The control of approximately 70% of the world's proved oil reserves by the 13-nation OPEC (Energy Information Administration, 2005, p. 30) is just the beginning step toward understand the shifting scarcity values of crude oil supply relative to demand. The institutions governing oil deposits in South America are quite different from the institutions governing oil in the United States and Canada, as another example. On the demand side, changes in economic policies spurring or retarding economic growth have swung oil prices as well.

### 5.7 Public policy implications

Public policy has been driven by perceptions of resource availability. Resource pessimism and even defeatism, nurtured by a natural-science-inspired worldview of finiteness, has inspired government intervention in the name of husbanding supply for the future. But the rationale behind such policymaking has it backward. DeGregori explained:

> If resources are not fixed but created, then the nature of the scarcity problem changes dramatically. For the technological means involved in the use of resources determines their creation and therefore the extent of their scarcity. The nature of the scarcity is not outside the process (that is natural), but a condition of it (DeGregori, 1987, p. 1258).

"The process" most prominently includes the political economy of resource development. Property rights, taxation levels, price flexibility, and other variables can make the difference between timely resource development and nondevelopment/underdevelopment.[20] The crude-oil price explosion in the 1970s, for example, had more to do with government control of oil than a decline in nature's stock relative to demand (Adelman, 1995, p. 329; Bradley, 1989, p. 3). Today's historically high oil prices, similarly, have less to do with a sudden inadequacy of oil-in-place and more to do with access restrictions in the United States (in Alaska and offshore in the Atlantic and Pacific) and resource socialism/nationalism, political unrest and conflict in oil-rich nations abroad (in Iraq, Russia, Venezuela, etc.) (Bradley, 2004, p. 6). Such artificial scarcity, however, by increasing prices above free-market levels, accelerates mineral activity in new directions. Resource development is overstimulated in relatively free areas (such as the United States), and the development of crude-oil substitutes (such as tar sands and oil shale) is overencouraged.

## 6 Conclusion

The siren song of mineral-resource theory is that *minerals are fixed, and therefore depleting, resources*. This empirical lacuna of neoclassical theory, increasingly noted in mainstream economics, can be jettisoned in favor of a real-world operational theory. Erich Zimmermann's *functional theory*, embellished by other subjectivist insights, and informed by the empirical record, provides a distinct Austrian theory of mineral resources. Mineral resources are not unique because they cannot be synthetically

[20] Culture, too, can drive resource development and nondevelopment. An indigenous tribal population living on top of rich mineral deposits may reject development because of tradition or religious beliefs.

manufactured. They are unique because they are unevenly distributed in the ground where, from the viewpoint of resourceship, they are manufactured.

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