RESOURCE-BASED GROWTH THEN AND NOW

Gavin Wright
Stanford University
June 2001

Prepared for the World Bank Project "Patterns of Integration in the Global Economy"

Resource-based economic growth has had a bad press for some time. Adam Smith wrote:

> "Projects of mining, instead of replacing the capital employed in them, together with the ordinary profits of stock, commonly absorb both capital and stock. They are the projects, therefore, to which of all others a prudent law-giver, who desired to increase the capital of his nation, would least chuse to give any extraordinary encouragement..." (1776, p. 562).

Perhaps abetted by the intuition associating "primary" products with "primitive" modes of production, coupled with the Ricardian-Malthusian premise that nonrenewable resources are fated to diminish over time (since as gifts of nature they cannot be replenished), the impression has been prevalent for at least two centuries that economic progress entails moving away from natural resources into sectors based on knowledge, skills, capital and technology.

Recent studies in development economics add quantitative rigor to this impression. Summarizing extensive econometric research, Richard M. Auty writes: "Since the 1960s the resource-rich developing countries have underperformed compared with the resource-deficient economies" (1998, p. viii). Sachs and Warner (1997) report that the underlying adverse effect of a natural resource environment on per capita GDP growth is robust in the face of tests that control for institutional quality, the share of investment in GDP, changes in relative prices, and other variables. The inverse association between resource abundance and growth has been widely accepted as one of the stylized facts of our times, and is sometimes referred to as the "resource curse" hypothesis (Auty and Mikesell 1998, p. 6. See also Sachs and Warner [1999]).

Can it really be true that less equals more, that like King Midas, developing countries would be better off with smaller endowments of natural resources? Although models that generate this result have been developed, most researchers acknowledge that they do not know the underlying reasons for the reported econometric associations. There are good reasons to question whether these associations are true structural relationships inherent in the character of resource-based activity. Cross-country regressions are notoriously subject to selection bias. If countries fail to build upon their resource base productively, then measures of "resource dependence" (such as the share of resources in exports) may serve primarily as proxies for development failure, for any number of reasons that may have little to do with the character of the resources themselves.[1] Indeed, it is not clear that relating growth *rates* to resource *endowments* is an appropriate specification. Rodriguez and Sachs (1999) suggest that resource abundance serves to raise the *level* of GDP per capita, *ceteris paribus*, so that the apparent drag on subsequent growth rates is better understood as a convergence to steady-state from above. A transition of this character can hardly be called a "resource curse."

Above all, this literature recognizes that there are exceptions to the general rule, countries well endowed with minerals whose economies have in fact performed successfully in recent decades. If there are prominent exceptions, can it then be true that "the problems of mineral economies [are] inherent to the production function of mining..." (Auty 1998, p. 46)? Since most treatments of the phenomenon culminate sooner or later in a discussion of politics, it would seem that (to quote the same author) "the staple trap is a less deterministic outcome than Sachs assumes and owes more to policy choice" (Auty 1998, p. 40). What we may have, in other words, is a set of countries whose political structures and institutions have failed to support sustained economic development. One can well imagine that in a setting of fragile institutions and factionalized politics, windfall resource gains may be a mixed blessing. But on this reading, the underlying problems are not inherent in the resources themselves, and the successfully managed resource economies are the exceptions that prove this rule.

The present paper develops this perspective by highlighting a case of successful resource-based development that seems to have been neglected in the recent literature: the United States. Not only was the USA the world's leading mineral economy in the very historical period during

---

[1] This concern is especially acute in those studies for which resource-based sectors are taken to include crop-growing agriculture. The inverse relationships between resources and economic performance seem stronger for agriculture than for minerals and forest products. See Auty (1998, p. 7; Leamer et al [1999], pp. 38-39).

which the country became the world leader in manufacturing (roughly from 1890 and 1910); but linkages and complementarities to the resource sector were vital elements in the broader story of American economic success. The broad lesson that emerges from the US case is that what matters most for resource-based development is not the inherent character of the resources, but the nature of the learning process through which the economic potential of these resources is achieved. The main failing of the recent literature is to regard natural resources as "endowments" whose economic essence is fixed by nature. This characterization was not appropriate for US history, and it is no more appropriate for the resource-based economies of today.

To be sure, the USA was no ordinary country. It may also be the case, as Findlay (1995) and Findlay and Lundahl (1999) suggest, that opportunities for resource-based growth are more limited now than they were in the pre-1914 era. On both counts, the American example will probably not provide a simple recipe for today's developing nations to follow. But a close study of an exceptional case can illuminate the ingredients that mark the difference between success and failure in resource-based development. And as will be argued, these broader lessons are reflected in the divergent experiences of modern resource-based economies as well. For reasons of time and expertise, the emphasis here is primarily on minerals; but many of the implications carry over to forest products and other possibilities for resource-based development in the modern global economy.

The United States as a Resource-Based Economy

According to the figures of Angus Maddison, the United States overtook the United Kingdom in GDP per Worker-Hour as of 1890, and moved into a decisive position of world productivity leadership by 1913 (1991, Chapter 2 and Table C.11). Perhaps surprisingly, in the same historical phase the US also overtook the previous world leader in GDP per Worker-Hour, Australia. In a neglected footnote, Maddison writes: “In defining productivity leadership, I have ignored the special case of Australia, whose impressive achievements before the First World War were due largely to natural resource advantages rather than to technical achievements and the stock of man-made capital” (p. 45, note 1). Resource-based leadership, it seems, is a second-class variety, not to be confused with the real thing.

How unexpected it is, therefore, to find that in 1913 the United States was the world’s dominant producer of virtually every one of the major industrial minerals of that era (Figure 1). Here and there a country rivaled the US in one or another mineral – France in bauxite, for example – but no other nation was remotely close to the United States in the depth and range of its overall mineral abundance. Furthermore, there is reason to believe that the condition of abundant resources was a significant factor in shaping if not propelling the US path to world leadership in manufacturing. The coefficient of relative mineral intensity in US manufacturing exports actually increased sharply between 1879 and 1914, the very period in which the country became the manufacturing leader (Figure 2, derived from Wright 1990). Cain and Paterson (1986) find a significant materials-using bias in technological change in nine of twenty US manufacturing industries between 1850 and 1919, including many of the largest and most successful cases. A study of the world steel industry in 1907-09 put the US at a par with Germany in total factor productivity (15 percent ahead of Britain), but the ratio of horsepower to worker was twice as large in America as in either of the other two contenders (Allen 1979, p. 919). Resource abundance was evidently a distinguishing feature of the American economy; yet economists do not seem inclined to downgrade US performance on this account.

There are good reasons not to. The American economy may have been resource abundant, but Americans were not rentiers living passively off of their mineral royalties. Clearly the American economy *made* something of its abundant resources. Table 1 displays a list of US industries ranked by absolute growth of exports between 1879 and 1909. Raw cotton was by far the leader. After cotton, nearly all the leading categories were manufactured goods closely linked to the resource economy in one way or another: petroleum products, primary copper, meat packing and poultry, steel works and rolling mills, coal mining, vegetable oils, grain mill products, sawmill products, and so on. The only items not conspicuously resource-oriented were the various categories of machinery. Even here, however, some types of machinery serviced the resource economy (such as farm equipment), while virtually all were beneficiaries in that they were made of metal. These observations by no means diminish the country's industrial achievement, but they confirm that American industrialization was built upon natural resources.

The point is further reinforced by Table 2, which reports the same information for the years 1899-1928. The one eye-catching change is the leap of motor vehicle exports to the forefront. The US was at the time the world's undisputed leader in automobile technology, and in many ways the industry epitomized the success formula for American manufacturing. Yet this leading industry was pervasively influenced by resource abundance: in its manufacturing technique; in the material composition of the product; and in the gas-guzzling appetite of the vehicle itself. After autos, the list is similar to Table 1 in its resource orientation: among the leaders, we still see petroleum products, cotton, primary copper, steel works and rolling mills, coal mining, tobacco, sawmill products, and farm equipment. Among the newcomers are canned foods and mining machinery, also closely linked to the resource economy. In many respects the auto industry may be seen as a kind of meta-resource-based industry, built on a foundation provided by the extended list of resource-based industries below it in the table.

The Endogeneity of American Mineral Resources

There is a deeper reason to reject the notion that American industrialization should be somehow downgraded because it emerged from a setting of unique resource abundance: On closer examination, the abundance of American mineral resources should not be seen as merely a fortunate natural endowment, but is more appropriately understood as a form of collective learning, a return on large-scale investments in exploration, transportation, geological knowledge, and the technologies of mineral extraction, refining, and utilization. This case is set out in detail by David and Wright (1997), and may be briefly summarized here.

For one thing, the United States was not always considered minerals-rich. Writing in 1790, Benjamin Franklin declared: "Gold and silver are not the produce of North America, which has no mines." (In 18th century, "mine" referred to an outcropping or deposit of a mineral.) Harvey and Press note that prior to 1870, Britain was self-sufficient in iron ore, copper, lead and tin, and "Britain was easily the most important mining nation in the world" (1990, p. 65). US lead mine production, for example, did not surpass that of Britain until the late 1870s. Leadership in coal came even later. Despite a vastly larger area, US coal production did not pass Germany's until 1880, and Britain's only in 1900. Leadership or near-leadership in copper, iron ore, antimony, magnesite, mercury, nickel, silver and zinc all occurred between 1870 and 1910. Surely this correspondence in timing among so many different minerals cannot have been coincidental.

In direct contrast to the notion of mineral deposits as a nonrenewable "resource endowment" in fixed supply, new deposits were continually discovered, and production of nearly all major minerals continued to rise well into the twentieth century – for the country as a whole, if not for every mining area considered separately. To be sure, this growth was to some extent a function of the size of the country and its relatively unexplored condition prior to the westward migration of the nineteenth century. But mineral discoveries were not mere byproducts of territorial expansion. Some of the most dramatic production growth occurred not in the Far West but in older parts of the country: copper in Michigan, coal in Pennsylvania and Illinois, oil in Pennsylvania and Indiana. Many other countries of the world were large, and (as we now know) well endowed with minerals. But no other country exploited its geological potential to the same extent. Using modern geological estimates, David and Wright show that the US share of world mineral production in 1913 was far in excess of its share of world reserves (1997, pp. 205-212). Mineral development was thus an integral part of the broader process of national development.

David and Wright identify the following elements in the rise of the American minerals economy: (1) an accommodating legal environment; (2) investment in the infrastructure of public knowledge; (3) education in mining, minerals, and metallurgy.

US mineral law was novel, in that the government claimed no ultimate legal title to the nation's minerals, not even on the public domain. All other mining systems retained the influence of the ancient tradition whereby minerals were the personal property of the lord or ruler, who granted users rights as concessions if he so chose. This liberality was not entirely intentional, but emerged from the collapse of federal leasing efforts in lead mines between 1807 and 1846, and from the de facto nonintervention policy during the great California gold rush that began in 1848. The federal mining laws of 1866, 1870 and 1872 codified what was by then an established tradition of minimal federal engagement: open access for exploration; exclusive rights to mine a specific site upon proof of discovery; and the requirement that the claim be worked at some frequency or be subject to forfeit. Although the fuel minerals coal and oil have received separate treatment in the twentieth century, most US mining activity has been governed by the Mining Law of 1872, among the most liberal in the world.

It would be mistaken to view the encouragement to mining as flowing exclusively from a simple well-specified system of rights and incentives, because much of the best US mineral land was transferred into private hands outside of the procedures set down by federal law. Nearly six million acres of coal lands were privatized between 1873 and 1906, for example, mostly disguised as farmland. Most of the iron lands of northern Minnesota and Wisconsin were fraudulently acquired under the provisions of the Homestead Act. Nevertheless, whether through official or unofficial procedures, the posture of American legal authority towards mining was permissive and even encouraging well into the twentieth century.

This discussion may convey the impression that the rise of US mineral production was primarily an exercise in rapid exhaustion of a nonrenewable resource in a common-property setting. Although elements of such a scenario were sometimes on display during periodic mineral "rushes," resource extraction in the US was more fundamentally associated with ongoing processes of learning, investment, technological progress and cost reduction, generating a many-fold expansion rather than depletion of the nation's resource base. This assertion may be illustrated by the example of the United States Geological Survey. Established in 1879, the USGS was the most ambitious and productive governmental science project of the 19th century. The agency was successor to numerous state-sponsored surveys and to a number of more narrowly focused federal efforts. It proved to be highly responsive to the concerns of western mining interests, and the practical value of its detailed mineral maps gave the USGS, in turn, a powerful constituency in support of its scientific research. The early twentieth-century successes of the USGS in petroleum were instrumental in transforming attitudes within the oil industry toward trained geologists and applied geological science.

The third factor was education. By the late nineteenth century, the US emerged as the world's leading educator in mining engineering and metallurgy. The early leader was the Columbia School of Mines, opened in 1964; some twenty schools granted degrees in mining by 1890. After a surge in enrollment during the decades bracketing the turn of the twentieth century, the University of California at Berkeley became the largest mining college in the world. The most famous American mining engineer, Herbert Hoover – an early graduate of Cal's arch cross-bay rival, Stanford – maintained that the increasing assignment of trained engineers to positions of combined financial and managerial, as well as technical responsibility, was a distinctive contributing factor to US leadership in this sector. A manpower survey for military purposes in 1917 identified 7,500 mining engineers in the country, with a remarkably broad range of professional experience, domestic and foreign.

Technology and Increasing Returns: The Case of Copper[2]

Between 1900 and 1914, the copper mines in the United States produced more than ten times as much copper as did the mines of Chile; but even this vast differential was not based on superior geological endowment. Indeed, Figure 3 shows that Chilean copper production exceeded that of the USA until the 1880s, and nearly recovered its relative standing by the 1930s. During the 1880-1920 era of US ascendancy, however, there was no comparison. The rapid growth of US copper production illustrates the ways in which investment and technological progress can expand a country's resource base, effectively creating new natural resources from an economic standpoint.

The pure native coppers of the Great Lake region were indeed a remarkable gift of nature, but the capital requirements for profitable exploitation of this potential were immense. Along with the railroads, the copper companies of Michigan pioneered in the organization of the giant integrated business enterprise. Advances in the 1870s and 1880s reflected technological

[2] This section draws upon David and Wright (1997), pp. 237-240.

developments in drilling and blasting such as the use of nitroglycerine dynamite and rock drilling machines powered by compressed air. Steam engines were adapted to hoist ore from the deepest mines in the country, as well as in stamping and other surface operations. Beginning in the 1870s, national totals were augmented by production from newly discovered deposits in Arizona and Montana, but Michigan copper continued to grow absolutely until the 1920s.

What truly propelled the copper industry into the twentieth century was a revolution in metallurgy, overwhelmingly an American technological achievement. In the 1880s and 1890s, the major breakthroughs were the adaptation of the Bessemer process to copper converting and the introduction of electrolysis on a commercial scale for the final refining of copper. These advances made possible a nearly complete recovery of metal content from the ore. The dramatic new development of the first decade of the twentieth century was the successful application of the Jackling method of large-scale, non-selective mining using highly mechanized techniques to remove all material from the mineralized area – waste as well as metal-bearing ore. Complementary to these techniques, indeed essential to their commercial success, was the use of the oil flotation process in concentrating the ore. Oil floatation called for and made possible extremely fine grinding, which reduced milling losses sufficiently to make exploitation of low-grade "porphyry" coppers commercially feasible.[3]

Together these technological developments made possible a steady reduction in the average grade of American copper ore, as shown in Table 4. By contrast, in copper-rich Chile – where output was stagnant – yields averaged 10-13 percent between 1890 and 1910 (Przeworski 1980, pp. 26, 183, 197). From these facts alone, one might infer that the US had simply pressed its internal margin of extraction further than Chile, into higher-cost ores. But Figure 3 makes it evident that the real price of copper was *declining* during this period, confirming that the fall in yields was an indicator of technological progress. Indeed, there is an exponential link between yield reduction and the expansion of ore reserves, through a formula known to geologists as Lasky's Law, an inverse relationship between the grade of ore and the size of the deposit (Lasky 1950). Advances in technology thus led directly to an expansion of American mineral wealth.

---

[3] This account of copper technology draws upon Parsons (1933), Schmitz (1986, pp. 403-405), and Lankton (1991, chs. 2-4).

Capital requirements and the need for long time horizons made copper an industry for corporate giants, an organizational form in which the USA may also have had a comparative advantage. Large enterprises internalized many of the complementarities and spillovers in copper technology, but they also drew extensively on the national infrastructure of geological knowledge and on the training of mining engineers and metallurgists. Although the initial impact was primarily within US territory, ultimately these techniques and organizations were transportable internationally, and by the 1920s Chile's copper production was on its way back to world leadership, largely through American technology, expertise, and corporate organization.

Historians differ on the reasons for the Chilean lag. In the mid-nineteenth century, the Chilean industry was comparable to and probably superior to that of the US in its technological sophistication. But the supply of high-grade ores began to decline in the 1880s, and in contrast to the US, Chile did not respond to this deterioration with either new discoveries or technological adaptation. Political historians stress the lack of national consensus in support of the industry, and the predominance of revenue motives in government policy. Economists tend to emphasize the obstacles posed by large fixed capital requirements in transportation and other forms of infrastructure, as well as in mining and processing facilities. One might attribute the comparative performance to economies of scale at the national level, since the US had a much larger territorial area, and American copper benefited from engineering skills, geological knowledge, and transport facilities that were developed to support many other resources besides copper. Scale economies were not independent of the legal and political regime, however; in Chile, for example, the mining code discouraged the consolidation of individual mining claims.[4]

Whatever the precise mixture of explanation, the important point is that Chile's problem was not its mineral endowment, but its delay in developing its resource potential. The barriers were real, but large US companies found profitable what the Chileans did not, and investments by Guggenheim and Anaconda after the turn of the century began the long-term reversal of the industry's fortunes. Through massive investments in railroads, roads, steamships, water and housing, these private firms in effect created their own infrastructure.

---

[4] Accounts of the contrasting histories of the Chilean and US copper industries include Przeworksi (1980) and Culver and Reinhart (1985, 1989).

Resource-Rich Underachievers

What was true of Chilean copper was also true of other areas of the world that are now known to be richly endowed with mineral resources: Latin America, Russia, Canada, even Australia – a country whose economic performance has been impugned for its excessive reliance on natural resources. European settlement of Latin America was largely motivated by the search for precious metals; but the Spanish and Portuguese rulers had little interest in the possible spillover benefits of knowledge and techniques from gold and silver mining for broader mineral development. Table 5 deploys the same methodology as Table 3 to show that as of 1913, the countries of Latin America had barely made a beginning at exploiting their potential in zinc, lead, bauxite, iron ore, phosphate rock and petroleum. Contemporaries and historians have found many rationalizations for this pattern of underachievement. But the proximate impediment seems to have been a lack of accurate knowledge about the extent and distribution of mineral deposits. A 1913 report by Orville A. Darby, calling attention to enormous undeveloped deposits of high-grade iron ore in Brazil, attracted great interest in that country. Yet even in the 1930s experts were cautioning that "a belief that South America is a vast reservoir of untouched mineral wealth is wholly illusory" (Bain and Read 1934, p. 358). Somehow the illusions of the 1930s metamorphosed into real resource endowments within sixty years, as mining investments blossomed throughout Latin America in the 1990s.

Australia was a leading gold-mining country in the nineteenth century, but Table 6 shows that Australia was an under-achiever in virtually every other mineral, particularly coal, iron ore and bauxite. In a nation with a strong mining sector and a cultural heritage similar to that of the US, why should this have been so? Here too it is easy to identify adverse factors that may have discouraged resource exploitation. The population of Australia has been small relative to its area, and the harsh climate of the large desert areas has discouraged migration from the coast. But similar conditions prevailed in much of the western USA. States like Montana, Utah and Arizona are not famous for their gentle climates. Australian miners were highly skilled, but neither Britain nor Australia invested significantly in advanced mining education in the 19th century. Into the 1880s, most large Australian mines were managed by Cornishmen, who had much practical experience but were untrained in metallurgy and resistant to new technology.

What seems to have been missing in Australia was the atmosphere of buoyant expectations about the prospects for major new discoveries. Pessimism led to misguided policies and lack of survey effort. In 1938, when Australia had recently begun to export iron ore on a small scale and gave promise of expanding this traffic, the government imposed an embargo on all iron ore shipments in an effort to conserve the remaining supply – effectively raising a barrier to exploration that remained in place for the next 25 years. The policy was justified by a report to the Commonwealth in May 1938: "it is certain that if the known supplies of high grade ore are not conserved Australia will in little more than a generation become an importer rather than a producer of iron ore" (quoted in Blainey 1993, p. 337). As late as 1953, *The Economist* reported: "...although most surface deposits in Australia have now been discovered and developed, no complete geological survey has been made and it is impossible to say how many minerals lie, as they are said to lie in the Sahara, below the barren surface of the Australian Desert" (cited in Warren 1973, p. 17). When the policy regime changed in the 1960s, lifting the embargo and offering state encouragement to exploration and construction of new ore terminals, a rapid series of new discoveries opened up previously unknown deposits, not only of iron ore but of copper, nickel, bauxite, uranium, phosphate rock and petroleum. By 1967 proved reserves of high-grade iron ore were already more than 40 times the level of 10 years earlier (Warren 1973, p. 215).

Prior to the 1960s, Australians had indeed accepted any number of unscientific rationalizations for the absence of important minerals such as petroleum: oil could not be found south of the equator; Australia's rocks were too old to contain oil; the country had been so thoroughly scoured by prospectors that surely nothing valuable could remain to be found. But this very attitude could lead to lethargic and therefore self-confirming search behaviors. Geologist Harry Evans recalled his own classic "rational expectations" reaction when a search party from the Weipa mission on the Cape York Peninsula found extensive outbreaks of bauxite in 1955: "As the journey down the coast revealed miles of bauxite cliffs, I kept thinking that, if all this is bauxite, then there must be something the matter with it; otherwise it would have been discovered and appreciated long ago." Indeed there was nothing wrong with it: by 1964 Weipa held about one-quarter of the known potential bauxite in the world (Blainey 1993, p. 332).

The outlines of Canada's mineral history are similar if less extreme. The Geological

Survey of Canada was organized by Act of Parliament only in 1877, and did not issue a complete set of statistical returns until 1886. Nickel first appeared on the scene as a contaminating factor in copper refining. But after the discovery and commercial production of nickel-steel in France in 1885, the value of nickel as a mineral was soon recognized, and the area around Sudbury, Ontario, quickly became the world's largest producer of nickel. The largest firm, International Nickel, was attractive enough to be purchased by J.P. Morgan on behalf of the U.S. Steel Corporation early in the twentieth century.

Nonetheless, at the time of the world survey of iron ore resources conducted by the International Geological Congress in 1910, the Canadian correspondent reported that "in Canada comparatively little work of investigation has been carried on yet, and with the information at our disposal it would be impossible to venture to afford figures which could give even an approximate idea of what might be called iron ore reserves" (1910, p. 31). In its tabular summary, the Congress Report listed actual Canadian ore supplies as "Considerable" and potential ore supplies as "probably enormous." The report for the Yukon, Alberta and Saskatchewan frankly acknowledged "how difficult it is to come to any definite conclusions as to the available supplies of iron ores in such a large country as Canada, the greater part of which is practically unexplored" (p. 732). But failure to explore can often lead to the assumption that the resources are not there. As late as 1966, a distinguished Canadian economist wrote that Canada is not "rich in natural resources" relative to the United States (Dales 1966, p. 164).

Such relative assessments are questionable, because they depend upon on the extent of exploration, the technological sophistication with which exploration is carried out, and relative demand for various minerals. In the twentieth century, Canadians have been responsible for path-breaking innovations in metallurgy that significantly expanded the range of commercially exploitable ores (Dow 1985, pp. 214-223). In the year 2000, private-sector expenditures for mineral exploration in Canada were fifty percent larger than those in the United States, and significant new discoveries are regularly reported. Because of their experience and expertise, Canadian mining firms are now highly visible around the world. In 1999 there were over 3,000 mineral properties in more than 100 countries where Canadian companies were active; they accounted for 30 percent of large-company programs worldwide.

The Rise of Petroleum: Causes and Implications

The leading global mineral story of the twentieth century has been petroleum. In its origins and growth as an American specialty, petroleum illustrates the themes of this essay very well: mineral development as a knowledge industry; evolving institutional relationships among government agencies, academic institutions, and private corporations; and national economic strength emerging from a resource base. The usefulness of the liquid mineral originally known as "rock oil" was first recognized in the United States, which dominated world production for more than a century. New discoveries led to an ever-widening range of uses in the twentieth century. Oil-using technologies spread around the world under American influence. It would seem to be a classic example of a nation building comparative advantage around its resource base. Yet we now know that from a world perspective, the United States was not particularly well endowed with petroleum. Paradoxically, American technology launched a worldwide, century-long process of movement away from the use of a mineral for which the United States has enormous reserves (coal) in favor of a liquid mineral in which the domestic supply is drying up, and for which geographic linkages between resources and industry have been substantially weakened.

Before petroleum, the role of applied science in industry was negligible. When the first oil well was put down at Titusville, Pennsylvania, in 1859, the techniques used were well known from centuries of drilling deep wells for brine and water. As discoveries moved on to more difficult terrain, drilling was facilitated by technological improvements, such as the replacement of the cable drill by the rotary drill. The rotary drill was first applied to petroleum 1900, and was responsible for bringing in the Spindletop gusher of 1901. In addition to advances in machinery, the application of petroleum geology was critical. The increasing use of oil as an energy source, and the expanding range of petroleum byproducts with market potential, provided the "demand push" for the systematic deployment of scientific knowledge. At the Columbia School of Mines, the curriculum included instruction in the drilling of artesian, brine and oil wells, while Charles F. Chandler, its dean and professor of applied chemistry, devised the flash-point test for kerosene, and was the foremost chemical consultant for the industry at the time. During the 1880s and 1890s several pioneer American geologists were employed as consultants by oil operators to help locate deposits in the Appalachian fields (Williamson et al 1963, p. 441).

The major breakthroughs for petroleum geology came in the two decades after the turn of the century. At least forty professional geologists and geological engineers were employed in California between 1900 and 1911, probably more than in any other oil region of the world at the time. Working with reliable field data published by the U.S. Geological Survey, these early graduates of the University of California and Stanford were influential in popularizing the anticlinal theory of the structure of oil-bearing strata. While the major elements of the theory had been worked out before 1900, the discovery in 1911 of the rich Cushing pool in Oklahoma dramatically demonstrated that anticlines were favorable places to find oil. In 1914 the Oklahoma Geological Survey published a structure-contour map of the Cushing field clearly indicating that the line separating oil from water was parallel to the surface structure contours. For the next 15 years most new crude discoveries were based on the surface mapping of anticlines. Prior to the 1920s, oil development outside of the US and Canada was almost entirely based on surface seepage. Because of the absence of detailed structural maps, major potential fields in other parts of the world had been passed over (Owen 1975, p. 437).

It was not geology but this investment in geological knowledge that explains the long American domination of world oil production (Figure 4). Other producing centers did eventually emerge, most notably in the Middle East, which collectively passed the United States in 1960. The rich oil potential of the Middle East had long been suspected, but its exploitation was delayed by political turmoil and international rivalries. Informed people were aware even during World War II that the center of gravity of world production would shift to the Persian Gulf. But as late as 1948, estimated reserves in North America and the Middle East were closely matched. By the 1980s, total world reserves surpassed anything dreamed of in 1948. The Middle East held by far the largest share, but oil reserves in virtually every other continent have come to surpass those of North America (Figure 5). To some extent this trend towards globalization reflects the many years of depletion of the US stock. But the more important influence has been the spread of exploration around the world, using advanced science-based techniques for detection, and with drilling capabilities that make even deep offshore wells commercially viable. If all the oil extracted in the US since 1859 were put back in the ground, North America would still be a minor player in the world oil drama today.

Oil and Economic Development

The historical American specialization in petroleum was thus not primarily a matter of endowment but of learning. One might well question, however, just what contribution this historical path has made to American economic development in general. Many modern analysts believe that the advent of petroleum has led to economic deterioration if not ruin for "petro-states" such as Venezuela (e.g., Karl 1997). Does the extended American love affair with oil have any lessons to offer on this score?

The discoveries of oil in the San Joaquin Valley, at Signal Hill, Santa Fe Springs and Huntington Beach did not bring economic ruin to southern California.[5] Before 1900, California was a small, remote, peripheral economy, experiencing a long period of sluggish development. Between 1900 and 1930, California (not Texas) became the leading oil state in the nation, and the result was a "sudden awakening" of the regional economy. Spurred not just by jobs in the oil industry but also by the dramatic fall in the cost of energy, California's share of national income nearly doubled; contrary to Dutch disease models, the size of the state's manufacturing sector quadrupled. One clear lesson of the California oil history: do not restrict the indicators of progress to per capita income. With the rush of population, California's level of per capita income continued its downward convergence toward the national average. But the state was launched on its modern course of leadership in technology and economic organization.

The transition from coal to oil entailed learning of many kinds, as California became the world's first oil-fueled economy. Potential users had to "learn to burn" the new fuel, convert burners and establish fuel supply networks. The Southern Pacific Railroad began using fuel oil on a permanent basis after 1895, and switched over completely after 1900. The state's electric utilities and sugar refining led the way, as virtually all of the large fuel consumers switched. With oil came a commitment to the gasoline-powered automobile, as California came to symbolize the high-mobility American lifestyle of the twentieth century. Although opinions are undoubtedly divided about the value of this lifestyle for humanity, one cannot deny that the institutions of higher learning that petroleum geology helped to put on the map – Berkeley and Stanford to

[5] The discussion of oil in California is drawn from unpublished research by Paul Rhode. See Rhode (1990).

name only the two most prominent – have evolved into world-class research universities.

The developmental contribution of oil was not limited to California. With the rise of petrochemicals in the 1920s, one may say that petroleum was instrumental in the transition of American manufacturing from traditional mass production to science-based technologies. Prior to 1920, there was little contact between oil companies and the chemical industry. The rise of the US to world stature in chemicals was associated with a shift of the feedstock from coal tar to petroleum. Working in close partnership with M.I.T., New Jersey Standard's research organization in Baton Rouge, Louisiana, produced such important process innovations as hydroforming, fluid flex coking, and fluid catalytic cracking. As the chemical engineer Peter Spitz has written: "regardless of the fact that Europe's chemical industry was for a long time more advanced than that in the United States, the future of organic chemicals was going to be related to petroleum, not coal, as soon as the companies such as Union Carbide, Standard Oil (New Jersey), Shell, and Dow turned their attention to the production of petrochemicals" (Spitz 1988, p. xiii). Progress in petrochemicals is an example of new technology built on a resource-based heritage. It may also be considered a return to scale at the industry level, because the search for by-products was an outgrowth of the vast American enterprise of petroleum refining.

The Case of Norway

The reader may accept this analysis as history, and yet protest that it has little relevance for the newer oil-producing nations of the world. How could such newcomers expect to contribute to what is now an extremely advanced science-based world petroleum technology? In rebuttal, consider the example of Norway, in which the first commercial discoveries of oil occurred only in 1969. In many ways the Norwegian experience parallels that of California. Though not poor by world standards, Norway in the 1960s was remote and structurally underdeveloped. Yet in fairly short order, the country was able to reorient its universities and its traditional engineering skills from shipbuilding, to become a full partner in the adaptation of oil exploration and drilling technologies to Norwegian conditions. With the establishment of a state-owned company (Statoil) in 1973, and investment in the training of petroleum engineers at the Norwegian Technical University and Rogaland Regional College, "recipient competence" was transformed into "participant competence," making it possible to speak of an independent

Norwegian oil industry. The industry became expert at producing deepwater drilling platforms; initially designed to overcome immediate production bottlenecks, the platforms came to be export goods, as they proved useful for offshore drilling in other parts of the world. A distinctive approach to exploration developed at the University of Oslo's Department of Geology, focusing on the properties of different types of sandstone as reservoir rock and the flow of water and oil in sediment basins, has come to be known as the "Norwegian school of thought" regarding oil exploration. Together, these advances in technology and in the infrastructure of knowledge have effectively extended the quantity of Norway's petroleum reserves, and they have allowed Norwegians to participate in the process as well-paid professionals, not just as passive recipients of windfall economic rents.[6]

Granted, Norway sets a high standard for national administrative competence and open and participatory democracy. As Karl notes, the Norwegian civil-service state was "the complete antithesis of Venezuela" (1997, p. 217), where intra-governmental political conflict and rent-seeking repeatedly disrupted the work of the state-owned oil development agency (PDVSA). Yet even in Venezuela, the PDVSA has been able to maintain a relatively high level of efficiency and expertise, with considerable success in developing technologies appropriate for the unusual concentration of heavy oil in the Orinoco Belt. Building on a legacy of professionalism from the international affiliates prior to nationalization in 1976, and aided by collaborative research agreements with BP Petroleum (a company with Canadian experience in heavy oil), PDVSA developed a new fuel (Orimulsion) for use by power utilities and heavy industry. Orimulsion is considered to have great potential, because it has a potential for gasification, can be used in a combined fuel cycle, and is environmentally friendly (Brossard 1993, pp. 170-177). Because of it, Venezuela is now in position to make full use of its previously uneconomic "sleeping whale."

---

[6] I am not aware of any published literature in English on Norway's contribution to petroleum technology. The discussion here is drawn from unpublished research and conversations with Ole Andreas Engen, Odd Einar Olsen and Martin Gjelsvik of the Rogaland Research Institute in Stavanger, Norway. The reference to the "Norwegian School of Thought" comes from Appolon 2000: Research Magazine from the University of Oslo, pp. 28-29. Karl (1997) notes that Norway is an exception to her generalizations about the adverse effects of petroleum, but she does not discuss technological developments (pp. 213-220).

Minerals and Economic Development in the Modern Global Economy

Are mineral resources a sensible basis for economic development in today's world? One must acknowledge that certain things have changed over the past century. The rise of oil-based transportation was the first major crack in the breakup of the huge industrial concentrations that were dominant on the basis of locational economics, such as the "American Manufacturing Belt" in the northeast and midwest. Daniel Yergin portrays World War I as a metaphorical contest between the locomotive and the truck, the rigid technology of the past versus the high-mobility wave of the future (Yergin 1991, Chapter 9). The process of geographic dispersion was further advanced by electrification, the chief advantages of which were the speed at which power could be transmitted over long distances and the flexibility with which it could be deployed. Indicators of geographic concentration in manufacturing within the United States show a steady decline from the peaks of the 1920s through the 1940s, an indicator of underlying tendencies in a setting unconstrained by national boundaries (Kim 1995, Figures I and II). With the liberalization of world trade and the decline in world transportation costs, international differences in the costs of industrial inputs such as iron ore and coking coal fell to insignificance by the 1960s. For all of these reasons, industrialization behind the "natural protective barrier of distance" ceased to be a viable strategy for resource-producing countries. On the whole, these trends are favorable from a global perspective, because they have expanded opportunities for successful industrialization in countries with few natural resources on which to build. But does this imply that countries should not develop the resources they do possess?

The operational question is not whether countries should attempt to reinvent themselves as entirely different historical and geographic entities than they are in actuality – such things are not matters of choice. The practical policy issue is whether countries with resource potential should encourage investment, exploration, and research for the purpose of developing that potential to its maximum. Even the skeptics about resource-based development concede that policies to restrict exports in order to "conserve" nonrenewable resources have had disastrous consequences (Auty and Mikesell 1998, p. 47). But such writers continue to base their analysis on the erroneous assumption that "natural resources, in contrast to assets produced by capital and labor, represent an endowment to society" (*ibid.*, p. 45); or that natural resource industries, "which rely on exhaustible factors of production, cannot expand at the same rate as other industries" (Rodriguez and Sachs 1999, p. 278).

In reality, so-called "natural" resources require extensive investments before they are valuable – perhaps more so today than in the past – and the required investments include not just physical capital and transportation, but also the acquisition of knowledge about the nation's resource base and the development of technologies that increase the value of that resource base. The fact that "information" can be disseminated costlessly and instantaneously around the world by no means implies that location-specific knowledge is no longer valuable. If anything, the opposite is true in today's knowledge-based resource economy. The potential gains are far more than is implied by the classic phrase, "sowing the oil," so as to invest in entirely unrelated sectors. Because extending the "knowledge frontier" can extend a country's effective resource base through exponential relations such as Lasky's Law, it is entirely possible for resource sectors to lead an economy's growth for extended periods of time.

To be sure, there are risks associated with the resource-based choice. Sudden windfalls or unexpected "natural resource booms" may disrupt otherwise healthy industries, calling for a level of policy restraint that may be difficult to achieve. Still worse, resource booms that channel profits directly to the state may constitute irresistible temptations for corruption and rent-seeking activity. It may even be, as Ascher (1999) has argued, that resource sectors are peculiarly vulnerable to such policy failures. One should note, however, that the essence of the policy failures described by Ascher was not the excessive cultivation of the resource-based economy, but political interference with incentives to pursue an investment and exploration that would develop these resources more fully. At times of fiscal crisis, cash-poor governments in both Mexico and Venezuela chose to raid the investment budgets of the state-owned oil companies, crippling development programs for a decade if not longer (Ascher 1999, Chapter 6). The failure, in other words, was delay in developing resource potential. Statistical analysis of such episodes may tell us much about the pitfalls of resource management, but they do not justify a conclusion that resource development itself is mistaken as a national policy. By pointing instead to the successes of well-managed resource-based regimes, we can illustrate what is possible in today's world. And there are indeed many encouraging examples to choose from.

Australia

As Australia's mineral production has flourished since the abandonment of the passive resource conservation policies of the 1930s, the country has emerged as one of the world's leaders in mineral exploration technology. Not only has the reinvigoration of minerals contributed to Australia's current rank as the world's sixth wealthiest country – reversing more than a century of relative decline – but in the past ten years, income from Australian intellectual property in mining has grown from $40 million a year to $1.9 billion a year, a larger sum than that earned by the wine export industry. Industry leaders have recently put forward an ambitious technological vision known as the "glass Earth project," a complex of six new technologies that would allow analysts to peer into the top kilometer of the Earth's crust to locate valuable mineral deposits. One executive stated: "The discovery of another Mt. Isa or Broken Hill – and we think they are out there – would lift us to fifth [place in the world]" (Cave 2001).

As environmental concerns increase, Australians also see promising opportunities to market the country's know-how and technology in cleaning up air, water and soil, recycling waste and eliminating pollution. According to the CEO of an environmental industry "venture catalyst:" "It is lovely that the environment benefits, but I'm really more interested in the business case and how it either saves costs or generates revenue. This field isn't recognized as a sector yet and Australia is well placed to take up a leading position" (*ibid.*).

Canada

Canada is also at the forefront of high-technology research in mineral exploration technologies. A program sponsored by Ontario is known as "Operation Treasure Hunt," the goal of which is to help identify new high-priority mineral targets of interest to the private sector. Its track record thus far illustrates the continuing importance of the "infrastructure of public knowledge." For example, discoveries by the Ontario Geological Survey of petalite-bearing pegmatites, beryl and spodumene in southeastern Ontario have led to aggressive exploration programs by several companies (Canadian Mining Journal January 1, 2001). The role of complementarities in search is illustrated by the nickel-copper-cobalt belt in Voisey's Bay, Labrador, found while exploring for diamonds (Mining Journal March 30, 2001).

Latin America

Having neglected its resources for generations, and having stifled incipient expansion in more recent decades through misguided state policies, the countries of Latin America seem to have turned the corner in the 1990s. Latin America is now the world's fastest growing mining region, receiving nearly thirty percent of mineral exploration spending worldwide in 2000, well ahead of Australia, Canada, Africa and the US (Clifford 2001). The business press regularly reports new discoveries, new investment projects to develop existing deposits, and new technological developments that extend the mining potential of particular areas. The leaders in this burgeoning new minerals growth are Chile, Peru and Brazil. Argentina has yet to experience major minerals success, but maintains a high level of exploration activity, knowing that "the country as a whole is underexplored compared to its neighbors" (Mining Journal April 20, 2001).

Chile

During the 1990s, the Chilean economy grew at a remarkable 8.5 percent per year. The mining industry has been central to this growth, accounting for 47 percent of all exports during the decade. The state-run copper commission expects mining investment to rise from $1.34 billion in 2000 to $1.94 billion in 2001, because of many new expansion projects currently underway. As the Mining Journal comments: "Without successful exploration, many such projects would not have come to fruition." The state mineral development company (Codelco) has been very active in exploration activity . Typical reported projects include: $7 million "to continue delineating the Gaby Sur porphyry copper deposit located in Region II;" "Codelco plans to spend US$20 million during 2001 quantifying reserves at the Mina project in the north;""Codelco was also active in a number of exploration joint ventures;" "Codelco is in talks to form a partnership with Ventanas, the copper smelter and refinery complex owned by another state body, Enami" (Mining Journal May 1, 2001). The relationship between ore grade and reserve quantity is illustrated by reports such as the one stating that "estimated resources at Escondida, which include resources used to define ore reserves, have increased significantly due to the release for the first time of low grade ore which is below the current concentrator cut-off grade but above the *economic* cut-off grade" (*ibid.*).

Peru

Peruvan mining is considered the region's "greatest success story." After the privatization program started in 1992, mining exports doubled to $3.01 billion by 1999, making Peru the world's second largest silver, bismuth and tin producer, sixth in copper and eight in gold. Mining Magazine reports: "There is a determination that the mining sector should play an even larger role in the economy and a number of legal instruments are now in place aimed at promoting foreign investment...As mining regimes go, Peru's can be fairly described as possessing an enabling environment" (May 1, 2001). That present development is far below potential is confirmed by such reports as: "Iscaycruz is one of the world's highest-grade zinc mines, but at present operates on only 1,000 ha of the 52,000 ha it holds in concessions" (*ibid.*).

Brazil

Brazil is the leading industrial nation of the region, and its economy is heavily dependent on the mining sector. Mining policy is undergoing considerable restructuring, a program that includes privatization, but which is also intended to encourage more powerful leadership from the national mining agency and the National Geological Service. Mineral exploration activities have significantly increased, with spending of $104US million in 2000, up from $44US million in 1999. At present, Brazil has only one copper mine and imports substantial amounts of copper. Because of a number of major discoveries in the Carajas region, in Para State, however, Brazil now expects "to occupy a prominent position in world copper production beginning in the period 2003-2005" (Mining Journal April 20, 2001).

Concluding Comments

This essay tries to show that mineral resources have growth potential, even in the new millennium. Nothing in this discussion, however, offers any guarantees against corruption, rent-seeking, and mismanagement of mineral and other natural resources. In other words, the potential may not be realized in practice. Even if high near-term returns are realized, unequal claims on these returns may generate extremes of income inequality, which in turn may foster lavish consumption for the few, and a neglect of investment in physical capital, human capital and the development of useful knowledge. All of these failings have been observed in the real world. They may afflict any economy, resource-based or not; but cross-country studies seem to show that resource-based countries are particularly susceptible.

Moreover, natural resource "booms" generated by rapid demand-side growth may not contribute positively to a country's economic health. Through "Dutch disease" effects, such booms may disrupt the progress of otherwise viable sectors of the economy. And a sudden influx of earnings channeled directly to the government may serve as a positive invitation to corruption and factional strife. Sachs and Warner (1999) suggest that natural resource booms often have little if any lasting positive effect on a country's growth.

One senses, however, that professional opinion on these matters has been overly influenced by the tumultuous events of the 1970s. Although the escalation of resource prices in that decade may have been triggered by supply-side restriction, from the perspective of most resource-based countries, it constituted an unanticipated demand-side boom, generating spectacular windfall gains. That experience stands in marked contrast to the 1990s, when mineral production steadily expanded in a context of relatively low world prices. Figure 6 conveys a sense of the pervasiveness of minerals expansion during the past two decades, in the countries under discussion. In contrast to the 1970s, this was a supply-side phenomenon, driven by ongoing advances in the technologies of search, extraction, refining, and utilization; in other words, by a process of learning.

The question then arises, are minerals a *sufficient* basis for a development program? A country may begin with a resource base, as the US did, but shouldn't the sign of progress be the transition into more highly processed products? The US parleyed its coal and iron ore into world class steel and auto industries. But many of today's resource-based countries are not doing this, and seem to be stuck in a permanent extractive phase. Because the "protective barrier of distance" has been so diminished by the decline in world transportation costs and improvements in communication, the possibilities for following what was once considered a "natural" path of industrial evolution may be much more limited in today's global economy. Although we lack good quantitative studies of how these structural relationships have changed over extended periods, this diagnosis of the resource-based development problem seems highly plausible.

Yet the path of working up the processing ladder is only one possibility. Failure to follow the US footsteps in this way *may* be a sign of missed opportunity, but the evidence presented here suggests that there are other viable paths. The key test is not how much processing is done within a country's boundaries, but whether the country is participating in the learning process, and whether the learning is structured so as to internalize development goals appropriately. As we have seen, progress can occur *within* the mineral sector, through learning that expands the effective resource base of the country. Government can advance this course of events by investing in appropriate human resources, and by sponsoring appropriately selected exploration and research projects. If skills and expertise are successfully developed, they may turn out to have spillover applications and marketability in areas rather different from the original targets. These possible payoffs certainly include the prospect that an intimate knowledge of the properties of indigenous resources can form the basis for elaborated products within the home country; the rise of petrochemicals in the US is an example of such symbiosis, where close familiarity with petroleum was a more important factor than transport costs. But if this scenario is not viable or appropriate because of international competitive conditions, this does not necessarily mean that resource-based paths are inherently circumscribed or inferior.

Thus we have an identification problem. If a country fails to move on from its extractive phase, the reason may be that it has failed to invest sufficiently in the knowledge aspects of its resource base. But the same pattern may instead reflect the outcome of a successful knowledge-based investment in resources. In order to diagnose the patient appropriately, we will have to look inside the black box of the learning process.

References

Allen, Robert (1979). "International Competition in Iron and Steel, 1850-1913," Journal of Economic History 39: 911-37.

Ascher, William (1999). Why Governments Waste Natural Resources. Baltimore: Johns Hopkins University Press.

Auty, Richard M. (1998). Resource Abundance and Economic Development. Helsinki: UNU World Institute for Development Economics Research.

Auty, Richard M, and Raymond F. Mikesell (1998). Sustainable Development in Mineral Economies. Oxford: Clarendon Press.

Bain, H.F., and T.T. Read (1934). Ores and Industry in South America. Harper & Brothers.

Blainey, Geoffrey (1993). The Rush That Never Ended: A History of Australian Mining. Melbourne: Melbourne University Press. Fourth Edition.

Brossard, Emma (1993). Petroleum Research and Venezuela's Intevep: The Clash of the Giants. Houston, TX: INTEVEP.

Cain, Louis P., and Donald G. Paterson (1986). "Biased Technical Change, Scale and Factor Substitution in American Industry, 1850-1919," Journal of Economic History 41: 153-64.

Canadian Mining Journal January 1, 2001.

Cave, Michael (2001). "Technology: How Well Australia Performs," Australian Financial Review March 31.

Culver, W.W., and C.J. Reinhart (1985). "The Decline of a Mining Region and Mining Policy: Chilean Copper in the Nineteenth Century," in T. Greaves and W. Culver (eds.), Miners and Mining in the Nineteenth Century. Manchester: Manchester University Press.

Culver, W.W., and C.J. Reinhart (1989). "Capitalist Dreams: Chile's Response to Nineteenth Century World Copper Competition," Comparative Studies in Society and History 31: 722-744.

Dales, J.H. (1966). The Protective Tariff in Canada's Development. Toronto: University of

Toronto Press.

David, Paul A., and Gavin Wright (1997). "The Genesis of American Resource Abundance," Industrial and Corporate Change 6: 203-45.

Dow, Alexander (1985). Prometheus in Canada: The Expansion of Metal Mining, 1900-1950," in Duncan Cameron (ed.), Explorations in Canadian Economic History. Ottawa: University of Ottawa Press.

Finley, Ronald, and Mats Lundahl (1999). Resource-Led Growth: A Long-Term Perspective. Helsinki: World Institute for Development Economics Research.

Harvey, C., and J. Press (1990). International Competition and Industrial Change: Essays in the History of Mining and Metallurg, 1800-1950. London.

International Geological Congress (1910). The Iron-Ore Resources of the World. Stockholm.

Karl, Terry Lynn (1997). The Paradox of Plenty: Oil Booms and Petro-States. Berkeley: University of California Press.

Kim, Sukkoo (1995). "Expansion of Markets and the Geographic Distribution of Economic Activities," Quartterly Journal of Economics 110: 881-908.

Lankton, L. (1991). Cradle to Grave: Life, Work, and Death at the Lake Superior Copper Mines. New York: Oxford University Press.

Lasky, S.G. (1950). "How Tonnage and Grade Relations Help Predict Ore Reserves," Engineering and Mining Journal 151:81-85.

Leamer, Edward E., Hugo Maul, Sergio Rodriguez, and Peter K. Schott (1999). "Does Natural Resource Abundance Increase Latin American Income Inequality?" Journal of Development Economics 59: 3-42.

Maddison, Angus (1991). Dynamic Forces in Capitalist Development. New York: Oxford University Press.

Mining Journal. March 30,2001; April 20, 2001; May 1, 2001.

Mining Magazine. April 20, 2001; May 1, 2001.

Owen, Edgar Wesley (1975). Trek of the Oil Fields: A History of Exploration for Petroleum. Tulsa: American Association of Petroleum Geologists.

Parsons, G.W. (1933(. The Porphyry Coppers. New York: American Institute of Mining and

Metallurgical Engineers.

Przeworski, J.F. (1980). The Decline of the Copper Industry in Chile and the Entry of North American Capital. New York: Arno Press.

Rodriguez, Francisco, and Jeffresy D. Sachs (1999). "Why Do Resource-Abundant Economies Grow More Slowly?" Journal of Economic Growth 4: 277-303.

Sachs, Jeffrey D., and Andrew M. Warner (1995). "Natural Resources and Economic Growth," Harvard Institute for International Development, Discussion Paper No. 517a.

Sachs, Jeffrey D., and Andrew M. Warner (1997). "Natural Resources and Economic Growth," revised version. Harvard Institute for International Development, Discussion Paper.

Sachs, Jeffrey D., and Andrew M. Warner (1999). "The Big Push, Natural Resource Booms and Growth," Journal of Development Economics 59: 43-76.

Schmitz, C.J. (1986). "The Rise of Big Business in the World Copper Industry, 1870-1930," Economic History Review 39: 392-410.

Smith, Adam (1776). An Inquiry into the Nature and Causes of the Wealth of Nations. Oxford: Clarendon Press, 1976.

Spitz, Peter H. (1988). Petrochemicals: The Rise of an Industry. New York: John Wiley & Sons.

Warren, Kenneth (1973). Mineral Resources. Newton Abbott: David and Charles.

Williamson, Harold F., Ralph Andreano, Arnold R. Daum and Gilbert C. Kiose (1963). The American Petroleum Industry: The Age of Energy 1899-1959. Evanston, IL: Northwestern University Press.

Wright, Gavin (1990). "The Origins of American Industrial Success, 1879-1940," American Economic Review 80: 651-668.

Yergin, Daniel (1991). The Prize. New York: Simon and Schuster.

Table 1: High Absolute Net Export Growth Industries, United States, 1879-1909

Industry	Net Exports, Millions of Dollars, 1909	Exports/ (Exp + Imp), 1909	Growth in Current Dollars, Millions of Dollars, 1879-1909	Growth in Constant Dollars, Millions of Dollars, 1879-1909
Cotton	404	.97	243	223
Petroleum products	105	1.00	67	102
Primary copper	82	1.00	79	75
Meat packing and poultry	153	.98	61	51
Steel works and rolling mills	27	.77	37	43
Coal mining	34	.91	33	32
Vegetable oils	37	.83	32	31
Farm equipment	26	.99	23	26
Special industrial machinery	22	.86	19	22
Leather tanning and finishing	25	.85	22	22
Grain mill products	51	.87	19	21
Sawmills, planing, and veneer products	26	.68	18	12
Fabricated wire products	9	1.00	9	10
Paving and roofing	10	1.00	10	10
Footwear (except rubber)	10	.98	10	9
Other commercial machinery and equipment	10	1.00	8	9
Other nonmetallic minerals	8	.98	9	8
Communication equipment	6	1.00	6	7
Logging	4	.62	10	7
Tools and general hardware	7	1.00	6	7
Other hardware	5	1.00	6	6
Motor vehicles	6	.72	6	6
Railroad equipment	5	1.00	5	6

Sources: M. L. Eysenbach, *American Manufactured Exports 1879-1914* (1976); R. E. Lipsey, *Price and Quantity Trends in the Foreign Trade of the United States* (1963), pp. 142-3, 146-7.

Table 2: High Absolute Net Export Growth Industries, United States, 1899-1928

Industry	Net Exports, Millions of Dollars, 1928	Exports/ (Exp + Imp), 1928	Growth in Current Dollars, Millions of Dollars, 1899-1928	Growth in Constant Dollars, Millions of Dollars, 1899-1928
Motor vehicles	500	.99	497	1,037
Petroleum products	447	.92	389	539
Cotton	877	.96	672	251
Primary copper	155	1.00	121	110
Steel works and rolling mills	120	.87	102	89
Farm equipment	112	.96	99	86
Special industrial machinery and equipment	105	.87	92	80
Coal mining	87	.94	77	71
Tobacco	201	.82	185	60
Sawmills, planing, and veneer products	79	.69	57	56
Other commercial machinery and equipment	57	1.00	45	39
Canning and preserving	62	.70	59	32
Tires and inner tubes	38	1.00	38	28
Construction and mining machinery	30	1.00	30	26
Machining tools and metalworking machinery	34	.98	27	23
Miscellaneous rubber products	29	.94	28	21
Paints and allied products	22	.87	21	13
Industrial organic chemicals	11	.88	20	12

Sources: M. L. Eysenbach, *American Manufactured Exports 1879-1914* (1976). Price deflators (1913 = 100) from Robert E. Lipsey, *Price and Quantity Trends in the Foreign Trade of the United States* (1963), pp. 142-143 and 146-147.

Table 3: U.S. Share of World Totals (%)

	1913 output	1989 reserves	1989 reserves plus cumulative 1913-1989 production	1989 reserve base plus cumulative 1913-1989 production
Petroleum	65	3.0	19.8	
Copper	56	16.4	19.9	18.5
Phosphate	43	9.8	36.3	15.4
Coal	39	23.0	23.3	
Bauxite	37	0.2	0.5	0.5
Zinc	37	13.9	14.0	15.6
Iron ore	36	10.5	11.6	7.4
Lead	34	15.7	18.1	18.8
Gold	20	11.5	8.6	8.4
Silver	30	11.7	16.3	17.6

Sources: David and Wright (1997), using data from: *Minerals Yearbook*; *The Mineral Industry--Its Statistics, Technology and Trade* (supplement to *Engineering and Mining Journal*); American Petroleum Institute, *Basic Petroleum Data Book*, Vol. X (September 1990); National Coal Association, *International Coal*; COE/EIA, *Annual Prospects for World Coal Trade* (1991).

Table 4: Average Yields of Copper Ore (%)

1800	English	9.27
1850	English	7.84
1870-1885	English	6.56
1880	American	3.00
1889	American	3.32
1902	American	2.73
1906	American	2.50
1907	American	2.11
1908	American	2.07
1909	American	1.98
1910	American	1.88
1911-1920	American	1.66
1921-1930	American	1.53

Sources: David and Wright (1997), using data from W. Y. Elliot *et al.* (1884), ‘International Control in the Non-Ferrous Metals,’ in R. Hunt, *British Mining and Metalliferrous Metals*, p. 374; Y. S. Leong *et al.* (1940) ‘Technology, Employment and Output per Man in Copper Mining,’ WPA National Research Project Report No. E-12.

Table 5: Latin American[1] Share of World Totals (%)

	1913 output	1989 reserves	1989 reserves plus cumulative 1913-1989 production	1989 reserve base plus cumulative 1913-1989 production
Petroleum	7.4	13.4	21.8	
Copper	12.6	32.1	26.5	28.9
Phosphate	0.0	5.2		
Coal	0.2	1.1	1.0	
Bauxite	0.0	27.2	29.4	30.0
Zinc	0.6	11.1	12.1	10.2
Iron ore	0.02	12.5	12.0	9.7
Lead	4.8	10.7	13.2	11.8
Gold	5.6	4.4	4.4	4.3
Silver	38.6	30.3	30.3	27.8

[1]South America plus Mexico and Caribbean.

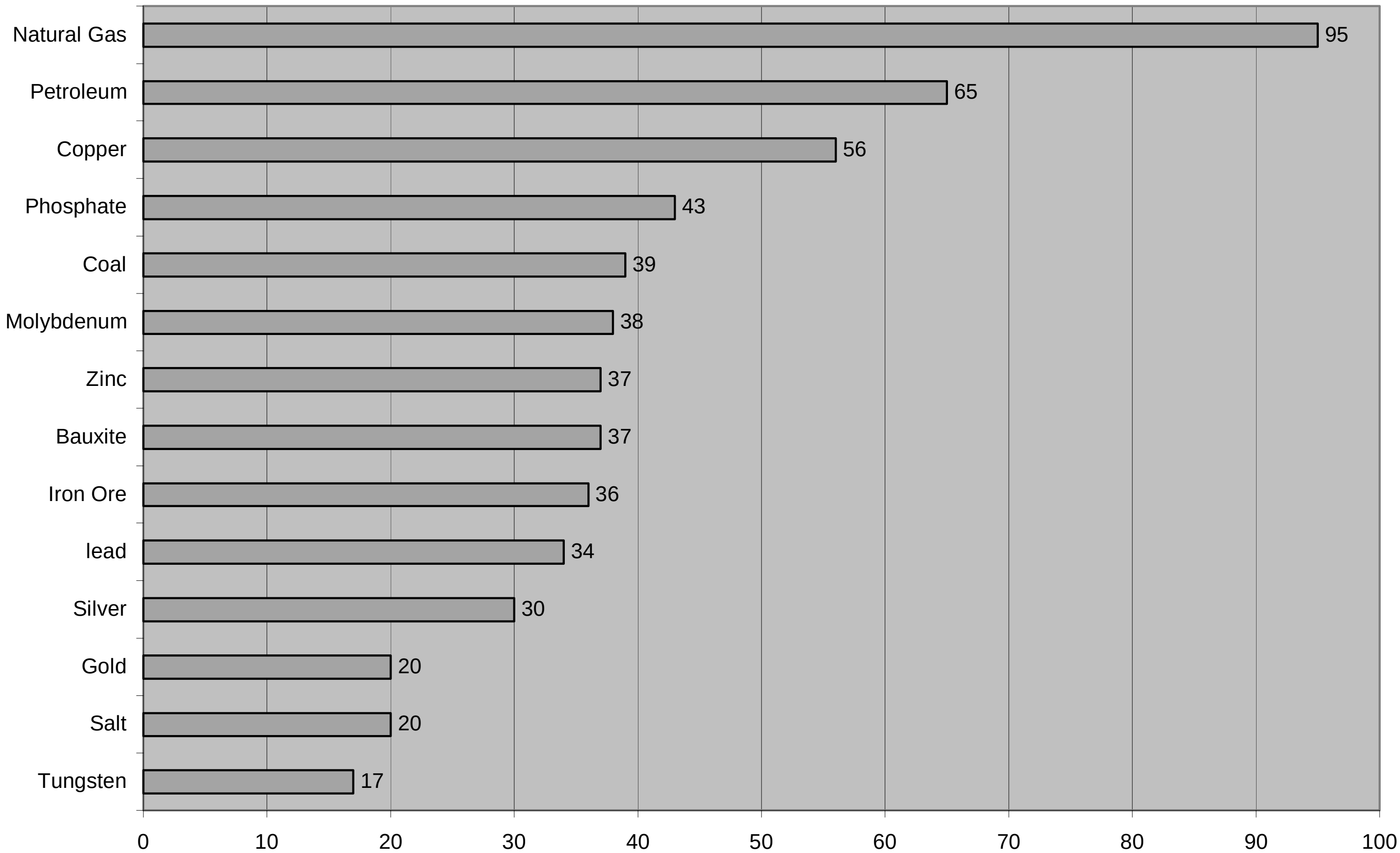
Sources: David and Wright (1997), using data from: *Minerals Yearbook*; *The Mineral Industry--Its Statistics, Technology and Trade* (supplement to *Engineering and Mining Journal*); American Petroleum Institute, *Basic Petroleum Data Book*, Vol. X (September 1990); National Coal Association, *International Coal*; COE/EIA, *Annual Prospects for World Coal Trade* (1991); C. J. Schmitz (1979), *World Non-Ferrous Metal Production and Prices 1700-1976*, London: Frank Cass; B. R. Mitchell (1983), *International Historical Statistics: The Americas and Australia,* Detroit, MI: Gale Research Co.

Table 6: Australian Share of World Totals (%)

	1913 output	1989 reserves	1989 reserves plus cumulative 1913-1989 production	1989 reserve base plus cumulative 1913-1989 production
Copper	4.7	5.1	3.8	5.5
Coal	0.9	8.6	8.9	
Bauxite	0.0	20.2	20.5	20.5
Zinc	21.8	13.2	11.1	13.5
Iron ore	0.06	9.9	9.1	14.5
Lead	21.8	20.0	15.3	16.8
Gold	9.9	4.3	3.4	3.6
Silver	7.5	10.0	7.5	7.8

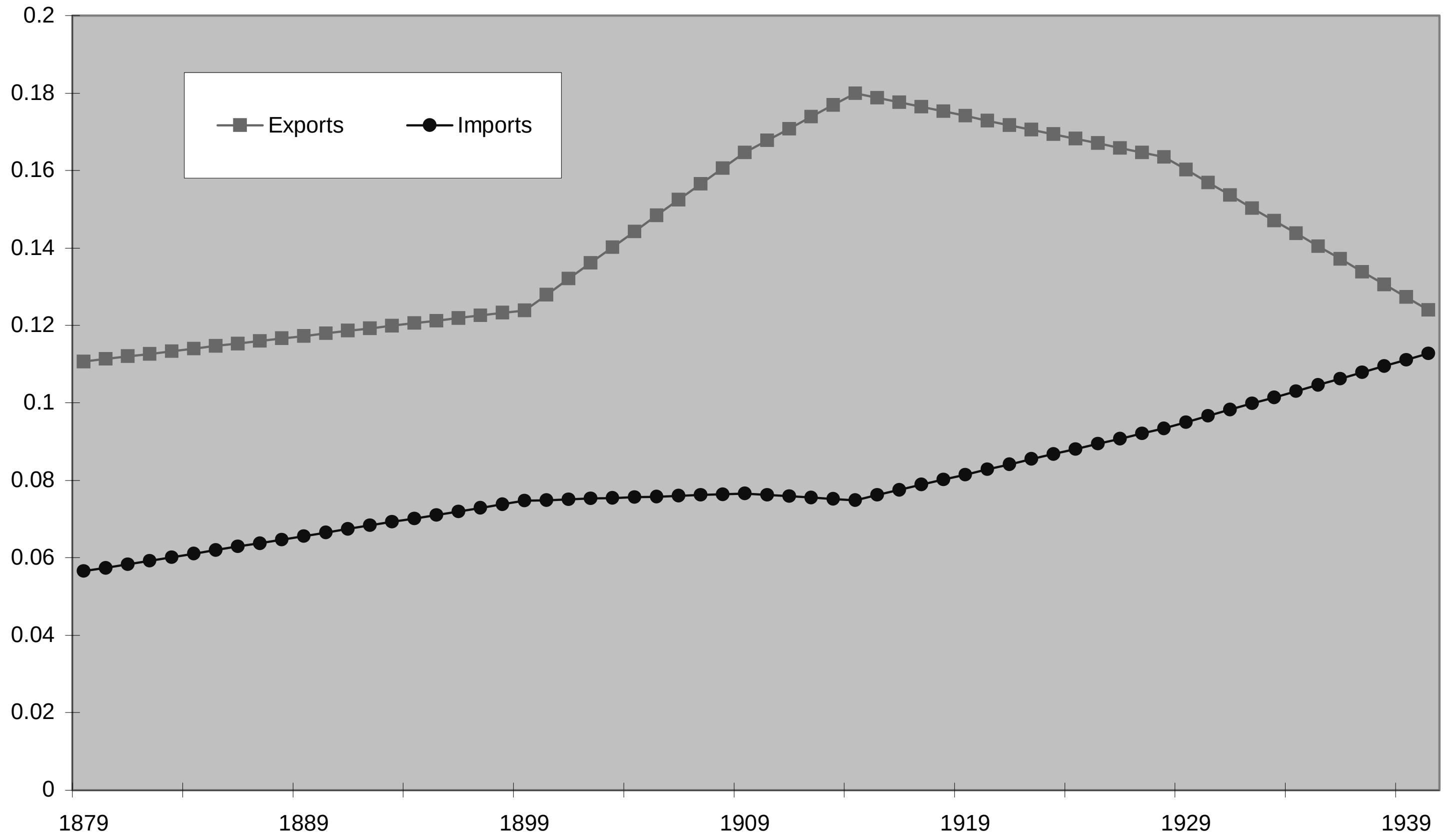
Sources: David and Wright (1997), using data from: *Minerals Yearbook*; *The Mineral Industry--Its Statistics, Technology and Trade* (supplement to *Engineering and Mining Journal*); American Petroleum Institute, *Basic Petroleum Data Book*, Vol. X (September 1990); National Coal Association, *International Coal*; COE/EIA, *Annual Prospects for World Coal Trade* (1991); C. J. Schmitz (1979), *World Non-Ferrous Metal Production and Prices 1700-1976*, London: Frank Cass; B. R. Mitchell (1983), *International Historical Statistics: The Americas and Australia,* Detroit, MI: Gale Research Co.

Figure 1: U.S. Mineral Output, 1913 (Percentage of World Total)



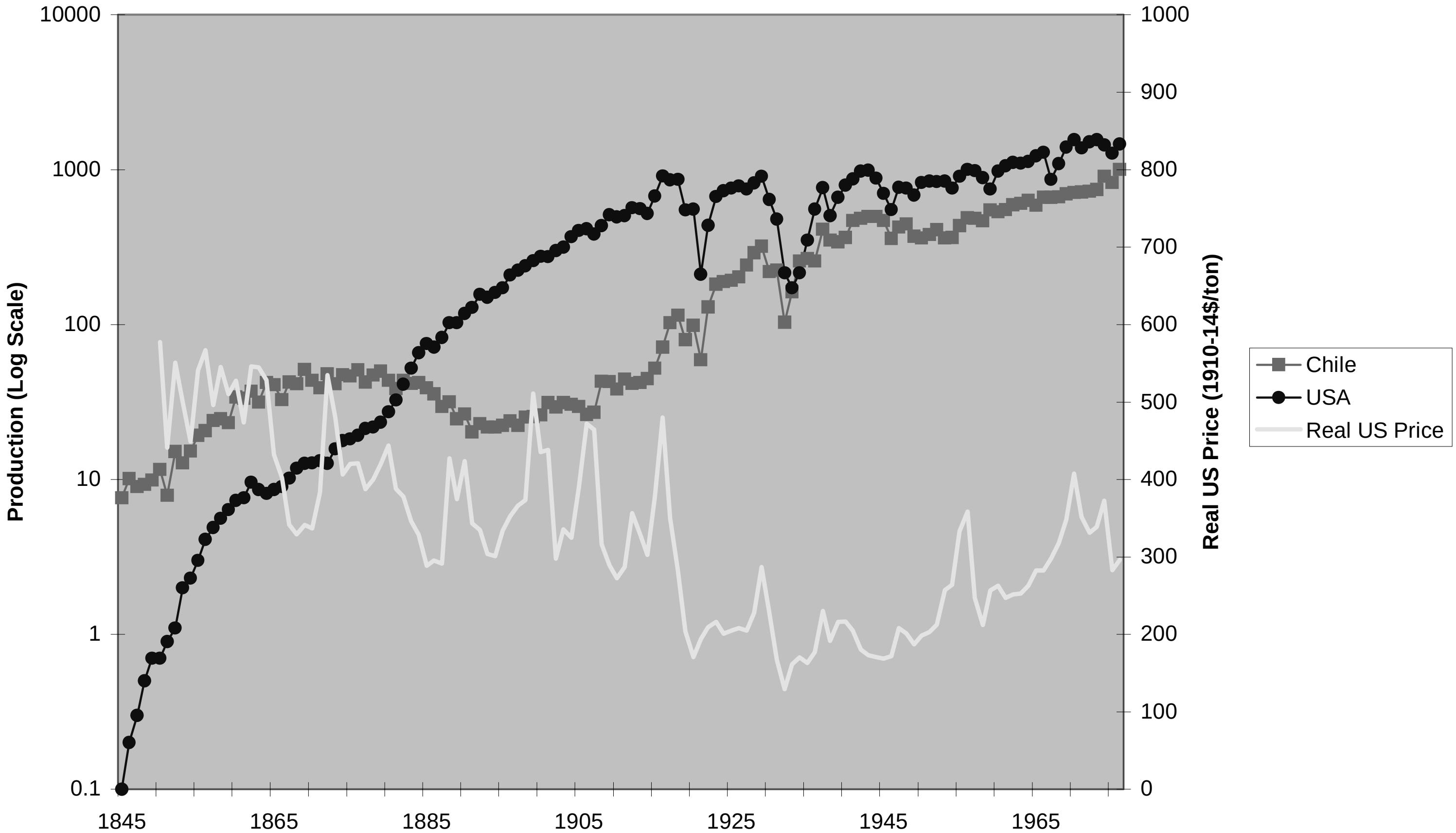
Sources: Reprinted from Wright (1990). Originally printed in Smith (1919), using data from U.S. Geological Survey.

Figure 2: Nonrenewable natural resource coefficients in manufacturing goods, 1879-1940 (1947 coefficients)



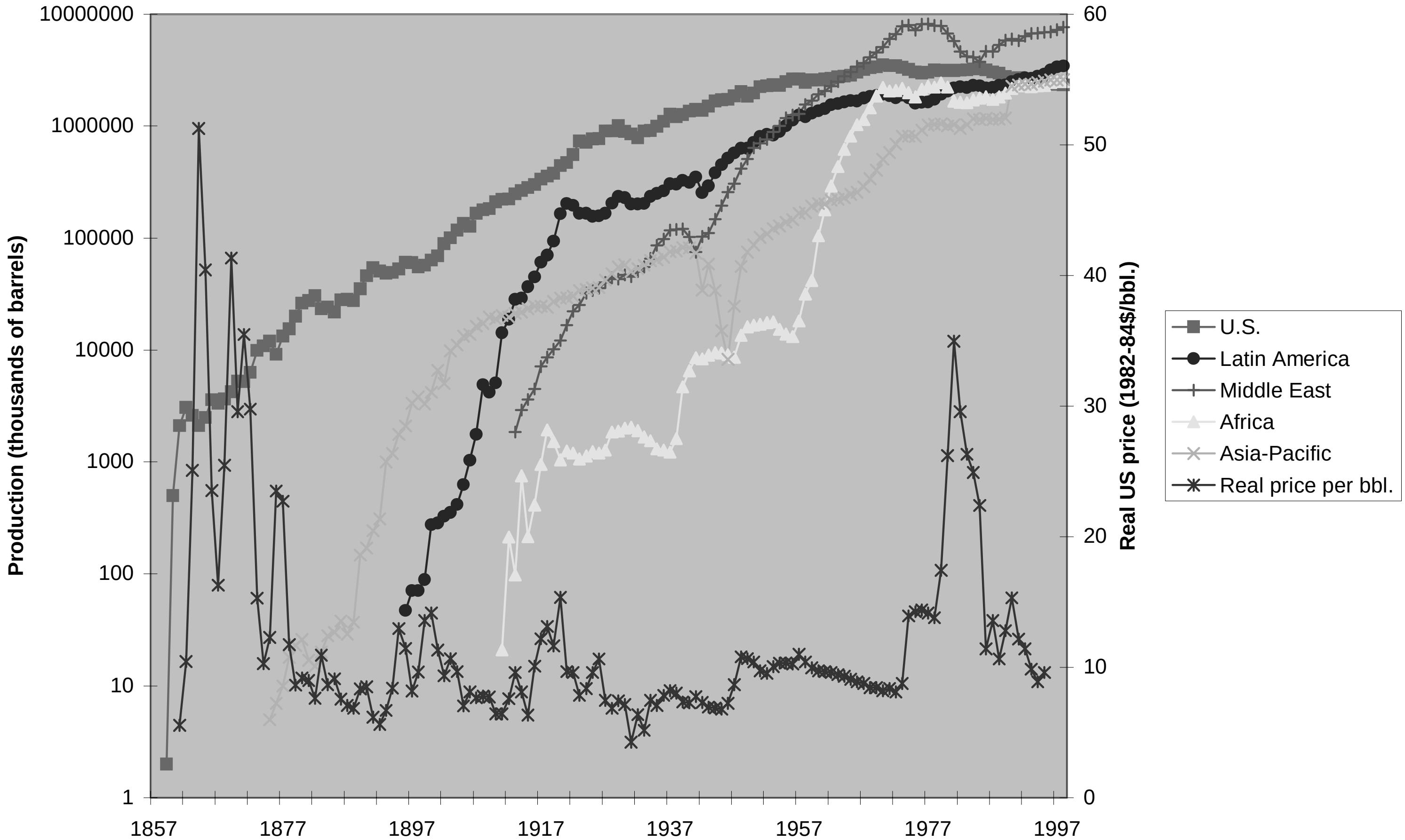
Source: Wright (1990). Data are available for the years 1879, 1899, 1909, 1914, 1928, and 1940 (the remaining portions of the graph are linearly interpolated).

Figure 3: Copper mine production, United States and Chile, and real U.S. price of copper, 1845-1976



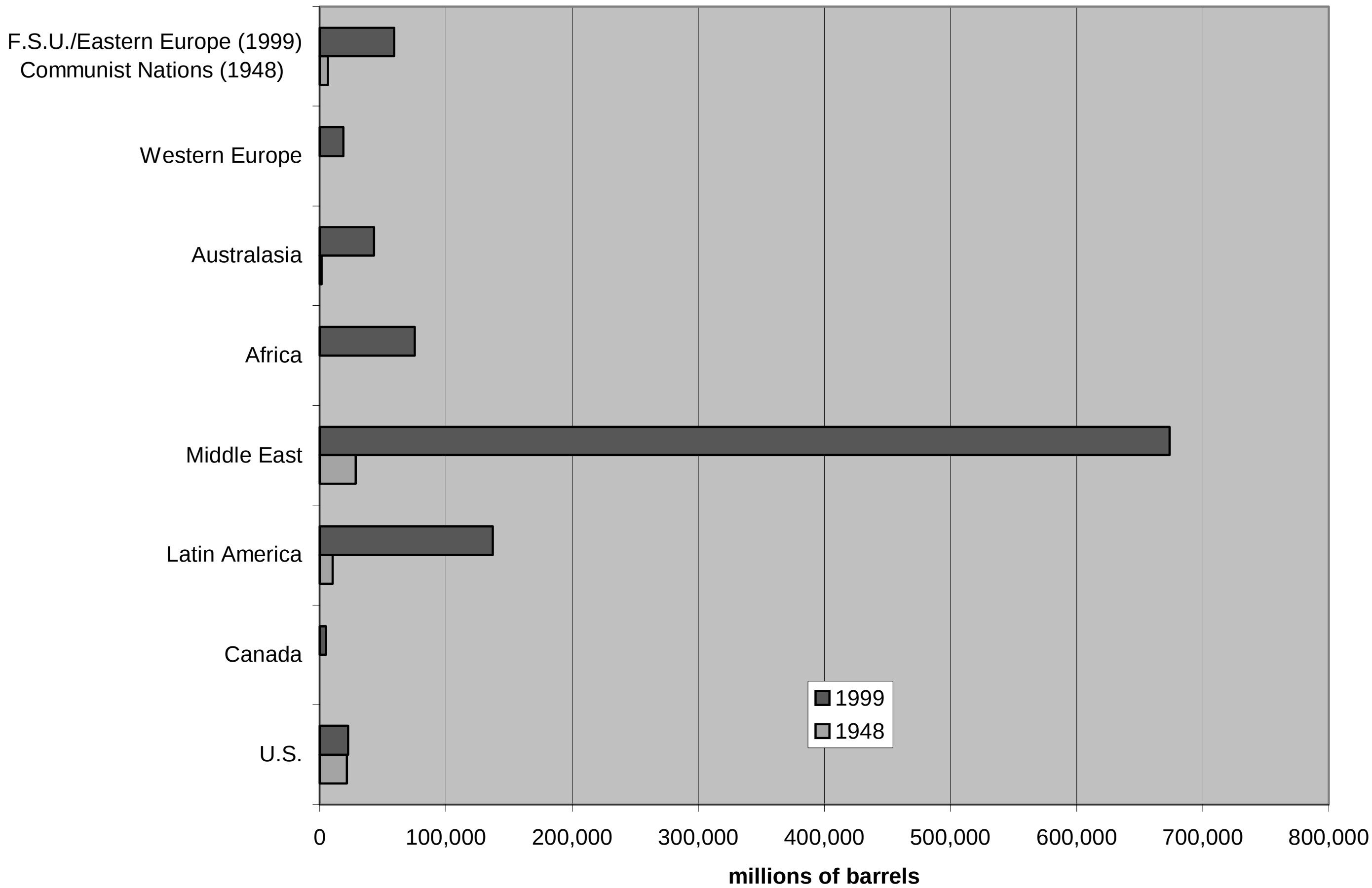
Sources: David and Wright (1997), using data from C. J.Schmitz, <u>World Non-Ferrous Metal Production and Prices, 1700-1976</u> (London: Frank Cass,1979), 63-78; 270-72).

Figure 4: Crude oil production by area and real US price of oil, 1857-1998



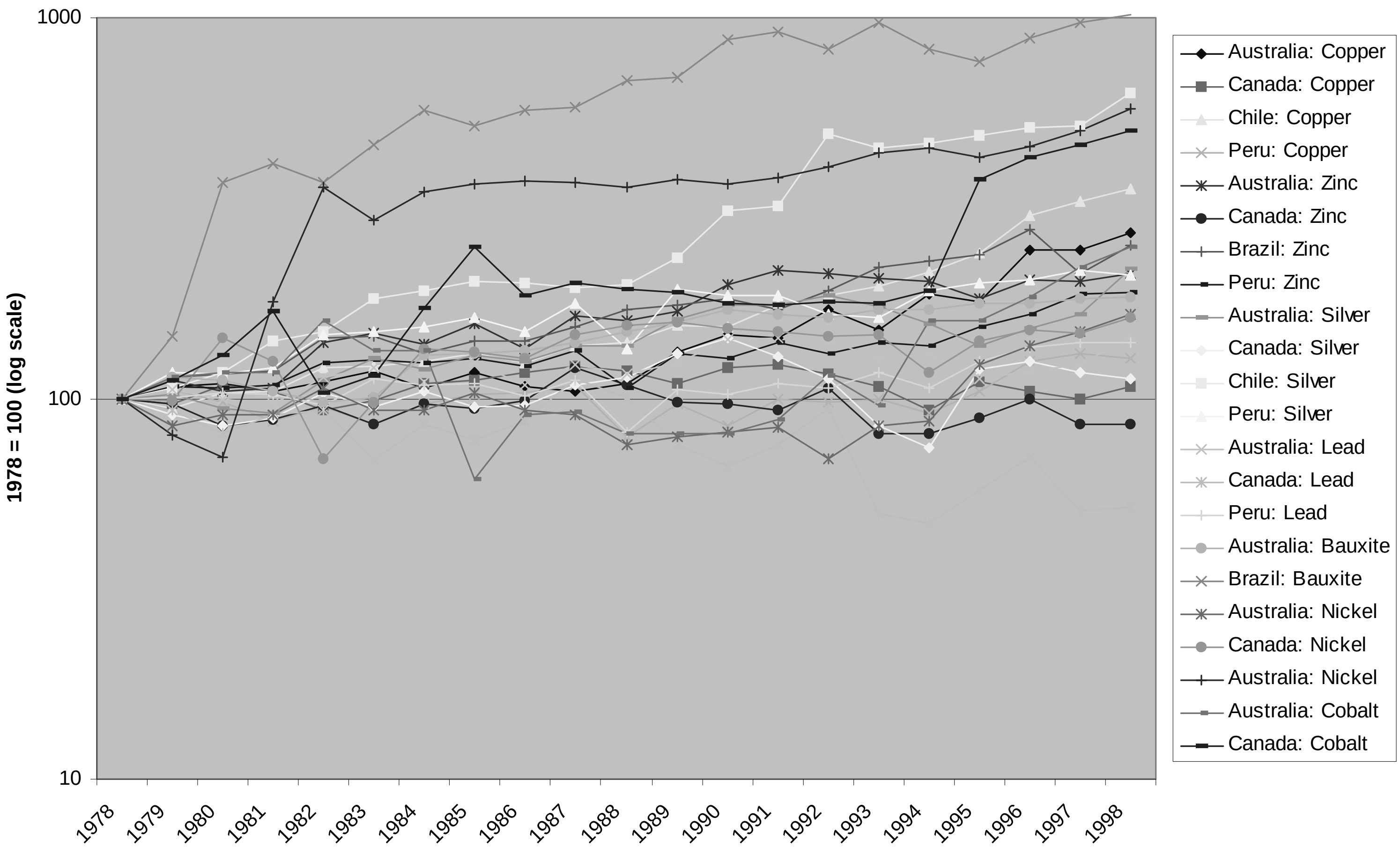
Sources: Production: American Petroleum Institute, *Basic Petroleum Data Book* (1999), Section VI, Table 1: "World Crude Oil Production by Area (Thousands of Barrels);" and Section VI, Table 10: "Historical World Crude Oil Production by Area: 1857-1946 (Thousands of Barrels)." Prices:1859-1931: U.S. Bureau of Mines, Mineral Resources of the United States; 1932-1976: Minerals Yearbooks; 1977-1995: U.S. Energy Information Administration, Monthly Energy Review. Price deflators: Bureau of Labor Statistics and Paul David and Peter Solar, "A Bicentenary Contribution to the History of the Cost of Living in America," Research in Economic History, vol. 2 (1977), pp. 1-80, Table 1, pp. 16-17.

Figure 5: World crude oil reserves, 1948 and 1999



Source: American Petroleum Institute, *Basic Petroleum Data Book* (1999, Section II, Table 1): "Estimated Proved Reserves of Crude Oil Annually as of January 1 (millions of barrels)."

Figure 6: Mine production, selected countries and minerals, 1978 - 1998



Then and now: Reimagining africaâ€™s future. Catalysing Investment for Transformative Growth.Â The contents of this report are based on the Economic Development in Africa Report 2014: Catalysing Investment for Transformative Growth in Africa, launched on 3 July 2014. All references to â€œdollarsâ€ are United States dollars. Sub-Saharan Africa: unless otherwise stated, this includes South Africa. Keywords: Natural Resources; Endogenous Growth; Ecological Footprint.Â We then show that the estimated coefficient on the Ecological Footprint is positive and statistically significant at the 1% level. This estimation result provides strong empirical support for the key prediction of our theoretical model, that is, more intensive utilization of natural resources in production leads to an increase in the economyâ€™s output growth rate.Â â€œGrowth with Exhaustible Natural Resources: Efficient and Optimal Growth Paths,â€ Review of Economic Studies 41, 123-137. Stokey, N. L. (1998). â€œAre There Limits to Growth?â€ Resource-based development undeniably involves important risks. Nonetheless, the resource curse â€“ if it exists - is at least no fatality, as the examples of Australia, Canada and the Scandinavian countries demonstrate. This paper argues that the serious challenges posed by resource-dependence, which include an increased vulnerability to external shocks, the risk of â€˜Dutch diseaseâ€™, and the risk of developing specific institutional pathologies, can be overcome, or at least very substantially mitigated, if accompanied by the right economic policies. It then analyses in detail what these â€œrightâ€